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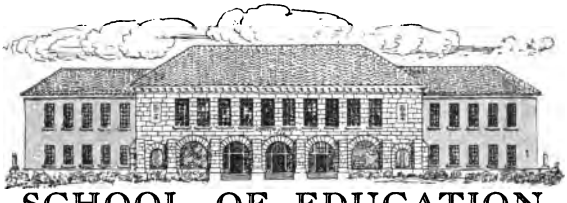
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A TEXT-BOOK

ON

PHYSIOLOGY.

FOR THE USE OF

SCHOOLS AND COLLEGES.

BEING AN ABRIDGMENT OF THE AUTHOR'S LARGER WORK ON HUMAN PHYSIOLOGY.

BY

JOHN WILLIAM DRAPER, M.D., LL.D.,

AUTHOR OF

A "TREATISE ON HUMAN PHYSIOLOGY," AND OF A "HISTORY OF THE INTELLECTUAL DEVELOPMENT OF EUROPE," ETC.

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PREFACE.

A DESIRE has been frequently expressed by professors and teachers who have used my large work on "Human Physiology," that I should publish an abstract of it, suitable for use as an elementary text-book in colleges and schools.

I have accordingly in this work endeavored to satisfy that wish, and to furnish a book sufficiently simple and compendious for such general use, and yet representing the state of the science at the present day.

Among my original contributions to the science, many of them first printed in various periodicals, and introduced into the previous larger work and also in this, I may mention the Electrical Theory of Capillary Attraction, Explanation of the Selecting Action of Membranes, Cause of the Coagulation of the Blood, Theory of the Circulation of the Blood, Explanation of the Flow of Sap, Endosmosis through thin Films, Measure of the Force of Endosmosis, Respiration of Fishes, Action of the Organic Muscle Fibres of the Lungs, Allotropism of Living Systems, New Observations on the Action of the Skin, Functions of Nerve Vesicles and their Electrical Analogies, Function of the Sympathetic Nerve, Explanation of certain Parts of the Auditory Apparatus, particularly the Cochlea and Semicircular Canals, the

Theory of Vision, the Theory of Muscular Contraction.

Of the wood-cuts, many are from photographs made by myself, particularly the microscopic photographs. The mode of producing these was first invented by me, and my "Human Physiology," published in 1856, was copiously illustrated with them.

The original engravings in this volume are, *Figs.* 3, 7, 8, 15, 16, 18, 19, 20, 21, 22, 23, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 39, 40, 41, 42, 47, 48, 49, 51, 52, 53, 54, 55, 56, 57, 58, 60, 67, 72, 73, 76, 79, 100, 103, 104, 105, 108, 109, 114, 115, 119, 120, 121, 122, 123, 124, 125, 126, 127. The rest are derived from standard authors. A list of them, duly accredited to their proper sources, will be found page 1, etc., of the larger work.

For the sake of facilitating the progress of the beginner, questions have been appended to each page, as was done in my previous text-books on Chemistry and Natural Philosophy. Their utility has been generally recognized by instructors.

JOHN WILLIAM DRAPER.

University, New York, 1866.

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HUMAN PHYSIOLOGY.

CHAPTER I.

Conditions of Life.—Nature and Sources of Substances supplied to the Body.—Annual Quantities required. —Animals do not create, but transform Substances. —Properties and Quantities of Matter received by the System.—Properties and Quantities of those it restores.—Heat of the Body arises from Combustion. —Cooling Agencies in an Animal.—Necessity of Repairs in the System.

For the maintenance of the life of man three chemical conditions must be complied with. He must be furnished with air, water, and combustible matter.

The supply of a part of these necessaries of life is adjusted to the urgency of the want. The act of breathing is incapable of delay, but the air is accordingly every where present, and always fit for use. We can bear with thirst for a little time, and the earth here and there furnishes her springs and other stores of water. But far otherwise is it in the obtaining of food. It is the lot of all animals to secure nourishment by labor, and even of men the larger proportion, both in civilized and savage countries, submit to a hard destiny. To obtain their daily bread is the great object of life.

What is the philosophical explanation of this necessity for a supply of air, of water, of food? Why is it that the system will bear so little delay?

The answer to these questions is an answer of ominous import. The condition of life is death. No part of a living mechanism can act without wearing away, and for the continuance of its functions there is therefore an absolute necessity for repair.

What are the chemical conditions necessary for the support of life? What is the condition under which the living body acts?

Life, far from being a condition of immobility, is therefore a condition of ceaseless change. An organism, no matter of what grade it may be, is only a temporary form, originating in myriads of particles passing through a determinate career. It is like the flame of a lamp, which presents for a long time the same appearance, being ceaselessly fed as it ceaselessly wastes away. But we never permit ourselves to be deceived by the simulated unchangeableness offered by such a natural object. We recognize it as only a form arising from the course the disappearing particles take. And so it is with man. He is fed with more than a ton weight of material in a year, and in the same time wastes more than a ton away.

To have a uniform standard of reference, we may assume one hundred and forty pounds as the weight of an adult healthy man. Now the constant consumption of food, water, and atmospheric air tends steadily to increase that weight, and in a very short time a disturbance arising from these sources would be perceptible, were there not some causes of compensation. But even after a year, if a state of health is maintained, the weight may remain precisely what it was, and this may continue year after year in succession. The consumption of large quantities of solid, liquid, and gaseous matter does not therefore necessarily add to the weight.

There are two periods of life for which this observation does not hold good. They are infancy and old age. During the former the weight increases from day to day, and during the latter it slowly declines.

If there be thus causes for the increase of weight of the living system, there are also causes for its diminution. Setting aside minor ones, these may be chiefly enumerated as loss by excreted, by transpired and expired matters. By transpired matters are meant such as escape under the form of liquids and gases from the skin; by excreted, such as escape from the kidneys; and by expired, vapors and gases escaping from the

In what respect does the animal body represent a flame? How much material does a man require in the course of a year? What is the standard weight of an adult man? How is it that that standard weight is maintained? To what periods of life does that principle not apply? What are the chief causes of diminution of weight?

lungs. There is, therefore, a tendency to an increase and a tendency to a diminution of the weight, and, in the condition of equilibrium we are considering, these must balance one another.

If a man of the standard weight abstains from the taking of water and food, a good balance will prove that in the course of less than an hour he has become lighter. If he still persists, it needs no instrument to detect what is going on; the eye perceives it, for emaciation ensues.

How, then, is it possible for a living being to continue at its standard, except the causes of increase are precisely equal to the causes of diminution? We may therefore assert that the sum total of food, water, and atmospheric air taken in a given period of time is precisely equal to the sum total of all the losses; for, if the receipts were greater, the weight must increase; if the losses were greater, the weight must diminish. Persistency in this respect proves equality, and the case is just as simple as in the common affairs of life; he who pays less than he receives grows rich; if his payments are more than his receipts, he becomes poor; but his condition is unchanged if his payments and receipts are equal. Infancy, old age, and manhood answer to these circumstances respectively.

From the army and navy diet scales of France and England, which of course are based upon the recognized necessities of large numbers of men in active life, it is inferred that about 2¼ pounds avoirdupois of dry food per day are required for each individual; of this about three quarters are vegetable and the rest animal. At the close of an entire year the amount is upward of 800 pounds. Enumerating under the title of water all the various drinks—coffee, tea, alcohol, wine, etc.—its estimated quantity is about 1500 pounds per annum. That for oxygen may be taken at 800 pounds.

With these figures before us, we are able to see how the case stands. The food, water, and air a man receives amount in the aggregate to more than 3000

Explain the manner in which the losses and receipts balance each other. What is the amount of dry food, of water, and of oxygen required annually? What is the annual aggregate of the receipts?

pounds a year; that is, to about a ton and a half, or to more than twenty times his weight.

The condition of equilibrium just set forth, moreover, leads to the conclusion that the aggregate weight of excreted, transpired, and expired matter is the same for the same period of time. In round numbers, we may take it at a ton and a half.

It can not be questioned that the materials rendered back to the external world, after having subserved the purpose of the animal and passed through its system, are compounds of those originally received as food, drink, and air, though they may have assumed in their course other, and perhaps, in our estimation, viler forms. Recognizing as indisputable the physical fact that not an atom can be created any more than it can be destroyed, we should expect to discover in the substances thus dismissed from the system every particle that had been taken in.

What, then, is man? Is he not a form, like the flame of a lamp or a waterfall, the temporary result and representative of myriads of particles that are fast passing through states of change—a mechanism, the parts of which are unceasingly taken asunder and as unceasingly replaced? The appearance of corporeal identity he presents year after year is only an illusion. He begins to die the moment he begins to breathe. One particle after another is removed away, interstitial death occurring even in the inmost recesses of the body.

From these general considerations we infer that the essential condition of life is waste of the body; and this not only of the body in the aggregate, but even of each of its particular parts. Whatever part it may be that is exercised is wearing away, and wherever there is activity there is death. And since parts that are dead are useless, or even injurious to the economy, the necessities simultaneously arise, first, for their removal, and, second, for repair. Much of the complicated mechanism of animal structures is for the accomplishment of this double duty.

What is the annual aggregate of the losses? Under what circumstances does interstitial death take place? What is the general use of the mechanism of animal structures?

Physiological Standard Table.

Diurnal Ingesta of a Man whose weight is 140 lbs. avoirdupois.

Weight of body	140.000
Water	4.109
Oxygen	2.192
Dry vegetable food	1.687
Dry animal food	.563

It is to be received as an axiom admitting no controversy, that organic systems, whether vegetable or animal, whether humble or elaborately developed, possess no power of creating material. Their function is of necessity limited to the mere transformation of substances furnished to them. From this it follows, even in the case of man, that the substances dismissed from the system are metamorphosed forms of those which have been received, and that, whatever their appearance may be, they must have arisen from the reaction of the food, water, and air upon one another.

This reaction we may proceed to view as a purely chemical result; for, casting aside all the hypotheses of the older physiology, and permitting ourselves to be guided by the harmonies of nature, we should expect to recognize in the changes taking place in organic systems, and in the phenomena attending those changes, the same results which arise in the artificial or experimental reaction of food, water, and air on each other. A very superficial examination of the facts shows at once the correctness of this expectation. On such a preliminary examination we now enter, premising it with some general remarks needful for our purpose on the nature and properties of food, water, and air.

1st. Of Food.—No article is suitable for food except it be of a combustible nature. Its chemical constitution must be such that if its temperature be raised to a proper degree with a due access of atmospheric air it will take fire and burn, and the products of its combustion must be carbonic acid gas and water, or those substances with nitrogen or its compounds.

2d. Of Water.—This may be taken as the type and

Does an animal create or only transform the substances it receives? How have the substances dismissed from the system originated? What are the chemical properties of food?

representative of all the various liquids used as drinks. It evaporates at any temperature, even at those lower than its freezing point, and in this evaporation produces cold. Water vaporizing from the skin absorbs 1114 degrees of heat, and hence exerts a most powerful refrigerating action. Over saline substances there are few bodies which exercise so general a solvent effect. In virtue of this property, it is enabled to introduce in the dissolved state such compounds as are wanted for the nutrition of the system, and in the same manner to carry away the wasted products of decay.

3d. OF ATMOSPHERIC AIR.—The active principle of the air is oxygen gas, the effects of which are moderated by the presence of a large quantity of nitrogen—four-fifths of the air consisting of this latter substance. Physiologically, we often use the terms atmospheric air and oxygen synonymously.

The chief materials a living being receives from the external world are, therefore, COMBUSTIBLE MATTER, WATER, OXYGEN GAS; and out of the action of these upon one another all the physical phenomena of its life arise.

Such being the nature and properties of the things received, we may next examine in the same general manner those dismissed from the system. Here, at the very outset, we encounter the important fact that they are oxidized or burned bodies.

1st. As respects the excretions. Their liquid part, water, is an oxide of hydrogen, of which, though the greater portion may not have been produced in the economy, yet a certain quantity unquestionably has. In them, too, may be found sulphuric acid, an oxide of sulphur; phosphoric acid, an oxide of phosphorus; and urea, the representative of bodies arising when processes of oxidation have been going on.

2d. The expired and transpired matters present similar burned compounds. At the head of these products stand carbonic acid gas, an oxide of carbon; and water, which, as we have already said, is an oxide of hydrogen.

What are the chemical properties of water? and of atmospheric air? What are the properties of the substances dismissed from the system? What are water, sulphuric, and phosphoric acids? Under what circumstances does urea arise? What are the chemical qualities of the expired and transpired matters?

We here omit any consideration of the nature or constitution of the fæcal matter, because much of it has never been properly in the interior of the system, though it has passed through the intestine.

The general result we arrive at is then, that the food consists of combustible matter, and that the substances dismissed from the economy are oxidized bodies. A burning must, therefore, have been going on, and this could only have been accomplished by the air introduced by breathing acting upon the substance of the body itself and its contents, and, to repair the waste which must have ensued, a due weight of food has been required. Since this, in its turn, as a part of the living mechanism, is destined to undergo the like destructive action, we may present the entire series of facts under consideration correctly by regarding them as arising remotely from the action of the air upon the food.

With this statement before us, we next inquire what ensues when substances appropriate for food are exposed in artificial experiments at a certain temperature to the action of atmospheric air.

A piece of flesh, or of any vegetable body, consisting of carbon, hydrogen, oxygen, and nitrogen, submitted to those conditions, undergoes combustion. Its carbon, by uniting with oxygen, produces carbonic acid, its hydrogen for the most part water, but a residue thereof, combining with the nitrogen, may give rise to the production of ammonia. If there be any sulphur and phosphorus present, they also burn, and salts of sulphuric and phosphoric acids are the result.

Such is what occurs outside of the body in a common case of artificial combustion where atmospheric air has access. The constituents of the food thus satisfy their chemical affinities, and the compounds we have mentioned arise. Now it is a fact of the utmost significance that the compounds thus originating from the direct artificial burning of matters proper for food are the very same that are dismissed from the animal system in which food has been submitted to the air introduced by

How do we know that combustion must take place in the body? What is the result of the artificial combustion of food? What are the products arising in the natural and artificial combustion of food?

respiration. They are such substances as carbonic acid, water, ammonia, sulphates and phosphates.

The facts thus set forth warrant the following statements. The matters a man receives as food are combustible bodies; those dismissed from his system have been burned. To that, as to any other such burning, oxygen gas is absolutely requisite. There is, therefore, a plain conclusion before us, which, in its far-reaching consequences, covers the whole science of physiology, and betrays to us the function discharged by every animal, viz., that oxidation is incessantly going on in the interior of the system through the agency of atmospheric air introduced by the process of breathing.

An animal, from this point of view, is an oxidizing machine, into the interior of which atmospheric air is constantly introduced. The active constituent, oxygen, satisfies its chemical affinities at the expense of those parts of the system that are wasting away. And as the act of breathing, that is, the introduction of this gas, takes place day and night, waking and sleeping, so too must the production and removal of burned bodies. To compensate for the loss, nearly 1000 pounds weight of combustible matter must be used in the course of a year, and, for reasons to be examined in detail presently, three quarters of a ton of water.

But carbon by uniting with oxygen can not turn into carbonic acid, nor can hydrogen turn into water, nor nitrogen into ammonia, without heat being produced. The very meaning we attach to the term indicates that every process of burning is attended with the liberation of heat.

In domestic economy, we protect ourselves from the cold weather of winter, or attain any high temperature we want by the oxidation of some of the forms of carbon, such as wood or coal, in fire-places or stoves. We know that for the production of a given quantity of heat a given weight of combustible matter and of air is required, and that by employing various mechanical contrivances for increasing the draught we can accelerate the burning.

How is it that animal heat is produced? What is the effect of oxygen in the interior of the body? Is there any relation between the amount of heat set free and the amount of oxygen consumed?

Man, in a state of health, maintains a nearly uniform temperature. Neglecting slight variations, to be hereafter critically examined, it is 98 degrees. For the most part, it is immaterial in what climate of the earth he may reside, whether in the cold polar regions or the torrid zone, he is so constituted that, either through the provisions of his own organization, or by resorting to the adventitious aid of clothing, or to special articles of food, he can maintain himself at about the same degree; and as all this heat arises from interstitial oxidation continually taking place, it is obvious that within certain limits he has control over it. Thus, in the winter he sometimes resorts to violent muscular action in order to increase the rapidity of respiration and the destruction of muscular tissue; for the greater the quantity of air introduced in a given period of time, the higher the temperature rises, just as when we close the door of a stove, or place a blower on an anthracite fire, an increased draught is occasioned and the quantity of heat is increased. To breathe with rapidity and depth is certain to raise the temperature.

On the contrary, in summer, when the heat is oppressive, we instinctively abstain from muscular exertion, tranquil and slow respiration goes on, and the temperature is kept down. Again, there are means of occasioning an increased liberation of heat by changing the nature of the food and using highly combustible material, such as the various kinds of alcoholic preparations. The chemical constitution of alcohol is such that in the act of burning, carbonic acid and water are produced with the liberation of so much heat that chemists find it one of the most suitable means of attaining a high temperature. On taking preparations of this substance, such as distilled liquors or wines, the first effect is the production of a genial warmth all over the body, intoxication eventually coming on as a secondary result.

These remarks are not limited in their application to our own species—the whole animal world furnishes us with commentaries on their truth. Man maintaining a

What is the temperature of man? Does it vary in different climates? In what manner may that temperature be incidentally raised? In what manner may it be reduced? What is the effect on the temperature when distilled liquors or wines are used?

temperature, as has been said, of about 98 degrees, other animals are at other degrees, some being cold-blooded and some hot. The particular point they reach depends, as direct observation shows, on the quantity of oxygen they consume, or, in other words, on their respiration. Birds, whose breathing mechanism is by far the most elaborate and extensively developed, have by far the highest temperature. The snake or the tortoise, whose rate of respiration is very slow, consume but little oxygen, and have a correspondingly low degree of heat. And in those creatures which at one period of the year are in full activity, but at another lie dormant or hibernate, as they begin to respire more slowly their temperature begins to decline, and when they have sunk into their winter's sleep their breathing is scarcely perceptible, and their warmth scarcely above that of the surrounding air.

In what has been thus far said we have been considering those operations of the system that tend to the production of heat, and the maintenance of the whole mass of the body at a temperature above that of the surrounding air. But it is obvious that provision must be made to prevent any undue rise, so that between those causes of elevation and these of depression a due equilibrium may be maintained. If a very large quantity of combustible matter, under the form of food, and about an equal weight of oxygen, are necessary for obtaining a proper heat, we should also recollect that nearly three quarters of a ton of water are consumed each year. The duty this water discharges we may next consider.

That duty is twofold: 1st. The removal of solid material in a state of solution; and, 2d. The production of cold by evaporation. The cooling agency is of most interest to us in our present inquiry, but a few remarks as regards the removal of solid matter may not here be misplaced.

1st. Water, then, exerts its solvent power for the re-

What is the connection between respiration and animal heat? How is it in the case of birds, snakes, and tortoises? How is it in the case of hibernating animals? What are the causes of the cooling of the body? Describe the double duties of water in the system.

moval of all those substances which, arising incessantly in the animal system, can not assume either the vaporous or gaseous state. In this condition are the different saline bodies, such as the sulphates coming from the destruction of the muscular tissues, as voluntary and involuntary motions are performed; or the phosphates produced by the destruction of cerebral and nervous matter. In the same condition stand nearly all the nitrogenized results of the destruction of the soft parts, and which are to a great extent to be removed as urea. Water dissolving with more or less facility these various bodies permits their escape from the system by the secreting action of the kidneys.

The skin is no inefficient auxiliary to the kidneys in effecting this removal of water charged with soluble matters. All over its surface are scattered in profusion the ducts of the perspiratory glands, consisting of a convoluted tubing abundantly supplied with blood-vessels. The final mode of action of these glands depends on extraneous circumstances. Most commonly the fluid is carried away under the form of a vapor or insensible perspiration, but when the secretion goes on more rapidly, or the dew-point of the surrounding air is high, it then accumulates as drops of sweat. The amount of water thus removed, even by insensible perspiration, is greater than might be supposed, yet it corresponds with the extent of the provision. The length of the water-secreting tubing in the skin of a man is about twenty-eight miles.

Thus by the action of the kidneys and the skin large quantities of water are dismissed, either under the liquid or vaporous form. A third organ is concerned in this important duty. It is the lungs. These, however, are limited in their operation to its exhalation as vapor or steam. That water abundantly escapes from them is plainly shown when the days are cold, the moisture as it comes from the respiratory passages condensing into a visible cloud when it encounters the air. It is estimated that the loss of water by the skin and lungs conjointly

What advantage is taken of its solvent power? Under what form is it removed from the system? What is the length of water-tubing in the skin? To what class of substances is the action of the lungs limited? How may it be proved that water is removed by the lungs?

is about 18 grains in a minute, of which 11 pass off from the skin and 7 from the lungs.

2d. Water also exerts a cooling influence, arising from its evaporation from the surface of the skin and the cells of the lungs. The difference between water in the state of an invisible vapor and in the liquid condition consists in this, that the vapor contains 1114 degrees of heat which the liquid does not. When, therefore, it evaporates from a surface of any kind, as from the skin, it obtains therefrom that large amount of latent heat, and so tends to cause the temperature to decline. Not that this is the only cooling agency at work. Radiation might also be mentioned; for, just as a warm, inorganic body cools by the escape of radiant heat from it, so too does a living being.

These considerations explain how an equilibrium of temperature is established. By the process of respiration there is a constant tendency to increase the heat; but by evaporation of water, radiation, and other cooling causes, there is a constant tendency to diminish it. A balance is struck between the two processes, and in man a temperature of 98 degrees is kept up.

This average temperature is, however, easily departed from. Through some trivial cause the cooling agencies may be interfered with, and then, the heating processes getting the superiority, a high temperature or fever comes on. Or the reverse may ensue. In Asiatic cholera, the constitution of the blood is so changed that its discs can no longer carry oxygen into the system, the heat-making processes are put a stop to, and, the temperature declining, the body becomes of a marble coldness characteristic of that terrible disease.

The animal mechanism is thus the focus of intense chemical changes, and great quantities of material are required in very brief spaces of time for its support. We have seen what is the use of the combustible matter employed as food, what of the water, what of the air, how, these reacting on one another, a high but regulated temperature is kept up.

On what does the cooling effect of water depend? How is the equilibrium of heat maintained? Under what circumstances is the standard temperature departed from?

Much of what has been thus far said has had reference only to the destruction of tissues. This waste of matter arises partly to give origin to the heat required by animals, and partly as a consequence of intellectual activity and muscular motion; for no movement can be made without a destruction of muscular fibre, and all mental and nervous actions imply the waste of a certain quantity of vesicular substance.

But of course such a destruction of tissue must be compensated by repair if a normal condition and health are preserved. The action of the air is not directly upon the food, for intermediately and temporarily the food is converted into the living mechanism. The dead material is awakened into life, and for a time, though only for a time, becomes a portion of the living and feeling mass.

The functions and actions we have been considering imply the provision of many complicated mechanisms. There must be means for effecting the introduction of the air; these, in man, depend on calling into operation its pressure. A system of tubes is necessary for its distribution to the points at which it is required, and in like manner a system is required for carrying away the wasted products of decay. The new material destined to replace the parts which are thus disappearing, and to keep the economy in repair, must be submitted to such processes of mechanical and chemical preparation that it may be dissolved in the blood, and carried wherever it is wanted. It must therefore be cut and crushed by teeth driven by powerful muscles, dissolved by acid and alkaline juices in digestive cavities set apart for that purpose. From these it must be taken by arrangements that can absorb it and carry it into the torrent of the circulation. Physical means must be resorted to, not only for the impulsion of these newly-absorbed nutritive juices, but likewise to drive the blood in its proper career of circulation. It is needless here to explain how the most refined principles of hydraulics are brought into play, or how forces of compression and elasticity are

How is it that the waste of so much matter arises? What mechanisms are requisite for the removal of waste and for repair? What operations must the food be submitted to before it can be introduced into the system?

introduced; how that there are valves which open only in one way to let the current pass, or how some of these, as in the like human contrivances, are tied down in their action by cords. Moreover, since it is required that the animal shall go in search of its food, muscles of locomotion, acting upon purely mechanical principles on the bony skeleton, must be resorted to, and so the animal structure becomes a most elaborate and complicated machine.

CHAPTER II.

OF FOOD.

The natural Subdivisions of Physiology.— Of Food: its Sources and Classification— its Value not altogether dependent on its Composition.— Of Milk: its Composition, and Use of its Water, Casein, Sugar, Butter, and Salts.— Variations in the Composition of Milk.— Of Bread.— Of mixed Diets.— Nutrition of carnivorous and herbivorous Animals:— Food formed by Plants and destroyed by Animals.— Uses of mixed Food and Cooking.

PHYSIOLOGY possesses a very great advantage over many other sciences in offering its leading problems and doctrines in a certain well-marked order or sequence, a connected whole, with only here and there points of digression, but those points often of very striking interest. Thus pursuing the train of reflections entered on in the preceding chapter, we should have to consider the nature of the food, the manner of its preparation by the process of digestion, the mechanism for taking it up from the cavities in which it has been so prepared, and that for distributing to every part. We should have to show the mode of its incorporation as a portion of the living mass, its duration in that condition, and the manner of its decay. We should have to describe by what physical means and through what mechanism the air is introduced to effect the destruction of the dying parts,

What are the natural subdivisions of physiology?

and how, as the consequence of this, a fixed temperature is maintained. The causes occasioning variations of this temperature, and the manner in which the wasted products are removed by the skin, the lungs, the kidneys, might next obtain our attention. The complicated machinery necessary to accomplish all these purposes requires to be made to act in unison in all its different parts, a condition introducing to us the nervous system. A consideration of the structure and gradual development of that system leads to the structure of the various organs of sense, and to the operations of the intellectual principle itself. Thus in succession we should have to treat of digestion, absorption, circulation, respiration, secretion, nutrition, and innervation, and to close the whole with the consideration of reproduction. This is the order I propose to follow, and shall devote this chapter to the nature and qualities of the food.

The supply of food to animals requires a more complicated provision than it does to plants, in which the elaborating organs, the leaves, presenting themselves superficially, are always in contact with the air, from which much of their nutriment is derived. And as one portion after another becomes exhausted, it is renewed by simple mechanical agencies, such as the trembling of the leaf, the warmth of the sun, or the winds.

Food comes spontaneously to plants, they therefore need no powers of locomotion. But an animal must seek its food, and for this purpose is endowed with locomotion, involving the destruction of tissue. In a chemical point of view, plants are organizing, animals destroying machines.

To obtain for animals the necessary supply of nutriment, the resources of nature are displayed in the most wonderful contrivances. According as their modes of life may be, one takes its food with its teeth, another with its lips, another with its fore member, another winds around it its whole body. The geometrical spider weaves a net, and lies in wait for his prey; the ant lion digs a pit in the sand. Some rely upon labor, some upon force, some upon fraud. Man depends upon all.

What are the sources of food for plants? In what manner is it brought to them? In the case of animals, how is the supply of food taken?

Viewed as regards its physiological distinction, the food is conveniently considered as of two kinds: Histogenetic or tissue-making, and Calorifacient or heat-making. Histogenetic food, of which albumen, casein, fibrin, are examples, furnishes the chemical substances —carbon, hydrogen, oxygen, nitrogen, sulphur, chlorine, phosphorus, iron, potash, soda, lime, etc. Calorifacient food, of which starch, sugar, oil, fat, are examples, furnishes carbon and hydrogen mainly. In consequence of this chemical constitution, tissue-making food is sometimes called nitrogenized, and heat-making non-nitrogenized food. The former is also sometimes designated nutritive, and the latter respiratory.

It is, however, to be distinctly understood that these divisions are only adopted for the sake of convenience, and that they have no natural foundation. Thus it will be found, when we examine the functions discharged by the fats, that though they are non-nitrogenized bodies, and are, therefore, considered as belonging to the class of respiratory food, there is every reason to believe that they are essentially necessary to tissue development, and that the metamorphoses of nitrogenized bodies can only go on in their presence. They are, therefore, as truly essential to nutrition as are the latter substances.

So, too, as respects the albuminoid bodies. They are not limited to nutrition. In their decay or descending metamorphosis in the organism, they give rise to the evolution of heat, and are at last dismissed as products of oxidation. They are, therefore, as far as this goes, as much respiratory food as are the fats themselves.

It has been supposed that the tissue-making power of any kind of food depends on the quantity of nitrogen it contains, and that its value may therefore be determined by chemical analysis. Upon this principle tables have been constructed, showing the agricultural worth of different articles of forage for domestic animals. But, as will be found hereafter, these tables are not of

How many physiological kinds of food are there? What is histogenetic food? What is calorifacient food? What are tissue-making, heat-making, nitrogenized, and non-nitrogenized food respectively? Are albuminoid bodies exclusively nutritive? Do they ever give rise to the evolution of heat? Are they ever respiratory? Does the value of food depend on its composition?

the use supposed. Without entering into details at present, the case of gelatin may be taken as an example; this, though a substance abounding in nitrogen, possesses no tissue-making value, but in reality belongs to the calorifacient class, and therefore its administration in the sick-room, under the various well-known forms of jellies, soups, etc., is altogether deceptive as regards any nutritive power, since it undergoes speedy oxidation in the system.

The same remark applies to tables showing the amount of caloric furnished by different varieties of heat-making food. The quantity of heat set free during the combustion of a substance depends not only on the nature of the elements composing it, but also on the particular states in which they occur. Combustibles may have the same chemical composition, but very different heating power.

Food, typically perfect, is presented by nature to the young of various animals. In milk, or in the egg, there must be whatever is necessary for the growth of the tissues, and for the performance of the functions. An examination of milk will therefore illustrate the essential characters of the different elements of food.

Composition of Milk.

Water	873.
Casein	48.
Sugar of milk	44.
Butter	30.
Phosphate of lime	2.3
Other salts	2.7
	1000.0

In this we notice, first, the large proportion of water present, almost nine tenths of the whole amount. The double duty of this water has already been mentioned, first, to remove from the system effete substances, second, to regulate the temperature by evaporation. We might have added that it also imparts a due fluidity to the blood. These are conditions as necessary to the infant as to the adult, and it should be remembered that two thirds of the weight of the body are water.

What is remarkable in the case of gelatin? On what does the amount of heat furnished by the combustion of food-articles depend? What is the composition of milk? State the relative quantity of water it contains. What is the use of the water?

Next follows the nitrogenized principle casein, closely related in composition to muscular flesh. It is the tissue-making, histogenetic, or nutritive element of the milk, and has been elaborated from the albuminoid substances of the mother's system. It is to be converted into the muscular and other soft tissues of the infant.

Casein is one of a group designated as the neutral nitrogenized bodies. Albumen, fibrin, and globulin belong to it. From an opinion that these all contain the same organic radical, they are often termed the protein bodies, a designation retained rather from its convenience than correctness. They appear to exist in two different physical conditions, soluble and insoluble in water; they all contain sulphur, and exhibit a proneness to pass into the putrefactive fermentation. As this takes place when they have reached a certain stage of decay, they act upon other bodies as ferments. Their constitution is said to be represented in common by the formula

$$C_{48}\,H_{36}\,O_{14}\,N_{6}.$$

Of the whole group, albumen may be taken as the type and most important member. Indeed, as will be found hereafter, in the process of digestion the others are invariably converted into modifications of it. The white of the egg and the serum of the blood are usually referred to as examples of albumen, though they differ in several particulars from one another. Albumen forms basic, neutral, and acid compounds. A basic albuminate of soda is found in the egg and in serum of blood.

Casein presents nearly the same constitution as albumen, but differs from it in its physical properties; for, while a solution of albumen is coagulable by heat, one of casein is not, but lactic and acetic acids coagulate it, though they have no such effect on albumen. While, so far as their protein nucleus is concerned, the two substances may be considered as agreeing in composition, they differ in this respect, that casein appears to contain a less proportion of sulphur and no phosphorus. It is interesting to remark that, during incubation, casein arises from albumen in the eggs of birds.

To what class of substances does casein belong? How much is there of it in milk? What is the imputed constitution of the protein bodies? Describe the properties of casein and albumen. What are the physical properties of casein?

Closely allied to albumen and casein, and having the same imputed protein nucleus, is fibrin. It likewise exists in two states, soluble and insoluble. Its solidification or coagulation can be produced by the action of sulphuric ether, which does not affect albumen. Moreover, in the coagulated state fibrin decomposes the deutoxide of hydrogen, but albumen does not. The most important difference between them is, that in the act of coagulation albumen shows no disposition to assume a definite structure, but fibrin does—fibrillating, as it is termed. The analogy of constitution and closeness of relation of the two substances is demonstrated by the fact that by nitrate of potash coagulated fibrin may be changed into albumen, and the same conversion is accomplished in the stomach by the digestive juices.

It has been affirmed, however, that fibrin contains a larger proportion of oxygen than albumen. This is sustained by physiological considerations respecting its origin.

These remarks on the composition and physical properties of casein, albumen, and fibrin, have been introduced for the purpose of illustrating the facility with which these bodies are mutually convertible, and more particularly for showing that there is nothing whatever mysterious in the casein or curd of milk, arising from the albuminous serum of the mother's blood, and being transmuted into the fibrin structure of the muscular tissues of the infant.

Returning now to our examination of the composition of milk, as set forth in the preceding table, we find that two respiratory elements are next upon the list: 1st. Sugar of milk. This is to be converted into lactic acid, partly by the agency of the saliva, and finally in intestinal digestion; 2d. Butter. This is the oleaginous or fatty portion; a part of it is to be deposited in the adipose tissues for a time of need, and a part, along with the lactic acid and excess of sugar, is to be burned at once for the production of heat.

The saline substance, phosphate of lime, is necessary

In what two states does fibrin exist? What is meant by fibrillating? Under what circumstances may fibrin change into albumen? Which probably contains the greater quantity of oxygen? What is the use of the sugar of milk? and of the butter?

for the earthy portion of the skeleton, and probably the reason of the introduction of casein, to the exclusion of other protein compounds, depends on the power it possesses of holding phosphate of lime in solution, not less than 6 per cent. of its weight of this earthy body being often obtainable from it. Among the other salts of the milk, chloride of sodium may be pointed out as of special importance. It undergoes decomposition in the system of the infant, its hydrochloric acid giving acidity to the gastric juice, its soda entering into the composition of the bile and various salivary secretions. It also imparts solubility to albumen, and, in some degree, regulates the facility with which that substance coagulates. It impedes the coagulation of fibrin.

An infant finds in its mother's milk whatever it requires for the growth of its own body. In its system the curd resumes the form of albumen, or passes into the condition of fibrin, and in this manner its muscular tissues are made. The butter is deposited in the adipose cells, or burned at once for the production of animal heat, a part of it, however, being incidentally consumed, as will be hereafter explained, in the fabrication of fibrin and for other histogenetic purposes. The phosphate of lime is carried to the osseous system, now in a state of rapid increase, and bone is formed from it.

But, though milk is so well adapted to the wants of infantile life, it is unsuited to the adult. Its nitrogenized principle, casein, though in sufficient quantity for the repair of muscular waste and development at the former period, is inadequate to these purposes at the latter, when destruction, arising from the incessant activity of the muscular system, is so greatly increased. It is interesting to remark how the composition of milk is modified when there is a necessity to meet these indications, its nitrogenized principle being increased in the case of animals such as the cow and horse, the young of which commence locomotion almost at birth, or at an earlier period than the human infant. This excess of casein is necessary for the repair of the resulting waste.

What effect does casein exert over the solubility of phosphate of lime? From what source is hydrochloric acid derived? Why is milk the most perfect type of food? What duties do its various parts discharge in the infant body?

The Constitution of Milk.

Source.	Casein.	Sugar.	Butter.
Goat's milk.....	80	40	40
Cow's milk.....	63	28	40
Human milk.....	32	36	29

This table presents an explanation of the unsuitableness sometimes remarked in the milk of the cow when used for the nourishment of children. Milk which is adapted to the wants of the calf is not adapted to the functional wants of the child. Experience has taught the nurse that these difficulties may in part be removed by diluting it with water and sweetening it with sugar, the effect of this being to reduce the percentage of the nitrogenized element, the casein, and to increase that of the respiratory, and so approximate the composition more closely to that of human milk.

Moreover, milk is not suitable as the sole nourishment of adult life, since it does not contain in sufficient quantity those phosphorized compounds necessary for the repair of the waste of the cerebral and nervous tissues, which at this period are much more active than in infancy.

From this consideration of the nature and properties of the food of infancy, we may pass to the examination of that of the mature period.

Experience has shown that, of all articles of food, bread made from wheaten flour meets best the requirements of the adult life of man. It seems to contain all that is necessary for support. A very simple analysis will show that it presents both the respiratory and nutritive elements.

If such flour be made into a paste with water, and be gradually washed with a larger quantity, an elastic coherent mass is left, and the water assumes a milky turbidity. After a time it becomes clear, through the settling of a white precipitate. This is starch, a member of the respiratory group. The elastic substance is glu-

In what respect does the milk of different animals differ? How may the milk of the cow be adapted to the use of the infant? Why is milk unsuited to adult life? From what substance is the most nutritious bread made? How may flour be separated into its constituent parts? To which class of elements does its starch belong?

ten; it is a true vegetable fibrin, mixed with another nitrogenized body, gliadine.

Thus, simply by washing in water, flour may be separated into two physiological elements, respiratory and nutritive, the former being the starch, and the latter the gluten. The relative quantity of these substances differs in different samples of flour, and, other things being equal, the greater the amount of gluten the more valuable the sample, because the more nutritious.

But civilized man has greatly improved on the simple diet furnished by Nature, and, without knowing the immediate or philosophical reason, has added articles to increase the respiratory element. The proverb says, "It is good to have bread, but it is better to have bread and butter." Let us examine why it is so.

Wheaten flour, in its relations to the animal system, is defective in one point—its respiratory element, the starch. Now the constitution of starch is, that in its dry state it contains much more than half its weight of water, none of its hydrogen being free, but all oxidized. It is, therefore, only by the use of very considerable quantities of bread that the necessary amount of respiratory food can be had for keeping up the temperature to the proper degree. But if butter be put upon the bread, the effect is different. In common with all oleaginous bodies, butter contains an excess of hydrogen, and therefore, under the same weight, possesses a very high heating power. The defect of the flour is thus compensated, and by the use of quite a moderate quantity a high temperature can be maintained.

From an examination of the diet-scales of the educational and invalid establishments of London, the prisons and the hospitals, the result has been obtained that the nitrogenized should be to the non-nitrogenized food in weight as one to five.

At a mature period of life, animals may be divided into two groups, first, the carnivorous, and, second, the herbivorous, or those that feed exclusively on flesh, and

To which class of elements does its gluten belong? In what respect is wheaten flour imperfect? Of what is starch to a large extent composed? What is the effect of the use of butter? What should be the ratio of nitrogenized to non-nitrogenized food? Into what groups may animals be divided?

those that feed on vegetable substances. Between these may, perhaps, be introduced a minor group, partaking of the manner of life of both.

The carnivorous animal finds in its prey all that is required for nutrition, and the discharge of its functions. Digestion under these circumstances is reduced to its simplest conditions, and is scarcely more than a process of solution. The digestive apparatus has but little complexity. The stomach may be regarded as a mere enlargement or pouch upon the alimentary canal, having, along with the intestine, the office of bringing the food into such a condition that it can pass into the circulation.

In the production of heat and motion the carnivorous animal consumes itself, and, through the oxidation incessantly going on by means of the air introduced by respiration, carbonic acid, ammonia, water, sulphuric and phosphoric acids are constantly forming.

On a superficial view it might be supposed that in the other group, the herbivorous, the case is quite different. These seem to spend all their lives in obtaining food. The ox or the horse, put out to pasture, is all the day long cropping the grass. On a comparison of the quality and nature of the food they take with the substance of which their bodies consist, there seems to be nothing in common. It was not, therefore, without reason that the earlier physiologists imputed to the digestive organs of this class the power of forming flesh and blood from vegetable matters. When, however, we come to a critical examination of the facts, we find that there is no essential difference between them and the carnivora.

When the expressed juice of vegetables is permitted to stand for a time, though it may have been clear at first, a turbidity sets in, and a flaky material is deposited. The substance thus possessing the power of spontaneous coagulation is identical in that property, and in composition, with animal fibrin. After its deposit, if the clear liquid be warmed to near the boiling point, it

How do these groups differ as respects their digestive apparatus? How does the carnivorous animal produce heat? How is the nutrition of herbivorous animals accomplished? What effects occur spontaneously in vegetable juices?

again becomes turbid, and a second nitrogenized substance subsides, which, from its quality of coagulating by rise of temperature and its analysis, is inferred to be identical with animal albumen. When this has been separated by filtration or otherwise, and the juice is slowly evaporated, there come on its surface skins of a body having the same qualities as casein; so fibrin, albumen, and casein pre-exist in plants.

Fatty matters of every description may also be extracted from vegetable products. From leaves, seeds, bark, wood, etc., oleaginous bodies can be obtained by the action of sulphuric ether. This liquid has the property of dissolving fat, and leaving it on subsequent evaporation.

It being thus understood that the food of the herbivorous animals contains nitrogenized bodies and fats ready formed, we have clearer views of the function of digestion in those tribes. It is not necessary to impute to their digestive organs the power of creating flesh and fat from vegetable matter. The office of the animal is merely to collect. The two groups being compared together, the carnivorous animal receives under less compass the required amount of nutriment, and its digestive apparatus is more compact. But the herbivorous animal must all the day long collect large quantities of food, out of which it may extract the little nutrient matter they contain. The carcass of an animal, seized by a lion, is almost all digestible, but it would require a very large amount of herbage or of grain to be supplied to an ox to make up the same quantity of albumen or fat. Hence the necessary complexity and size of the digestive organs of the herbivorous group, and hence many of their habits of life.

Universal experience, as well as direct experiment, proves that in the case of man health can not be maintained on a uniform diet, however it may be with animals. A mixed food, changed from time to time, seems to be essential.

What effects occur on heating vegetable juices? What on evaporating them? Do fats pre-exist in vegetable products? Describe the sources from which herbivorous and carnivorous animals respectively obtain their food. What is the cause of the difference of their digestive apparatus?

Undue excesses of albumen, oil, or starch, in the diet of an individual, produce a liability to arthritic, bilious, and rheumatic affections. An abstinence from fresh vegetables and fruits develops scorbutic, and a deficiency of oleaginous materials scrofulous disease. It is evident that a control over these affections may be obtained, or even their cure, to a considerable extent, accomplished, by suitable changes in the nature of the food. This is strikingly seen in the improvement of the health of sailors during long voyages, since the introduction of vegetable preparations or acid juices. In 1726, Admiral Hosier sailed from England to the West Indies with seven ships of the line, and lost his whole crew twice by scurvy. The circumnavigation of the globe is now often accomplished without the loss of a single man.

Tables of the value of food, as dependent on chemical composition, are of little use in the case of man. The art of cooking does not minister alone to the gratification of the palate, it lends a real assistance to the operation of digestion. New elements may not have been added, nor existing ones removed in submitting the food to the action of a high temperature, yet such a change is thereby impressed upon it that it becomes more capable of digestion, and more subservient to the wants of the economy.

Why is there a necessity for the use of mixed food? What is the physiological effect of cooking?

CHAPTER III.

OF DIGESTION.

TISSUE-MAKING OR HISTOGENETIC DIGESTION.

Nature of Digestion. — The digestive Tract. — The Mouth, Teeth, Stomach. — The Salivary Glands. — Different Kinds of Saliva.—Properties of mixed Saliva: its Quantity, Composition, and Functions.— The Stomach.— Gastric Juice.— Organs for its Preparation.—Manner of producing Chyme.—Influence of the Nerves.—Artificial Digestion.—Preparation and Properties of Pepsin.—Regional and functional Divisions of the Stomach in Animals and in Man. — Object of Stomach Digestion.—Peptones.— Use of Salt.—Digestibility of various Articles of Food.

BEFORE the food can be absorbed and carried to all parts of the system it must be submitted to certain preparatory operations. It is necessary to bring it into a condition of solution in water, or at least into a state of minute suspension in that liquid. Received in masses of a certain size, it is first cut and crushed into smaller portions by the teeth, and then brought from an insoluble into a soluble or suspended state by the chemical action of the digestive juices.

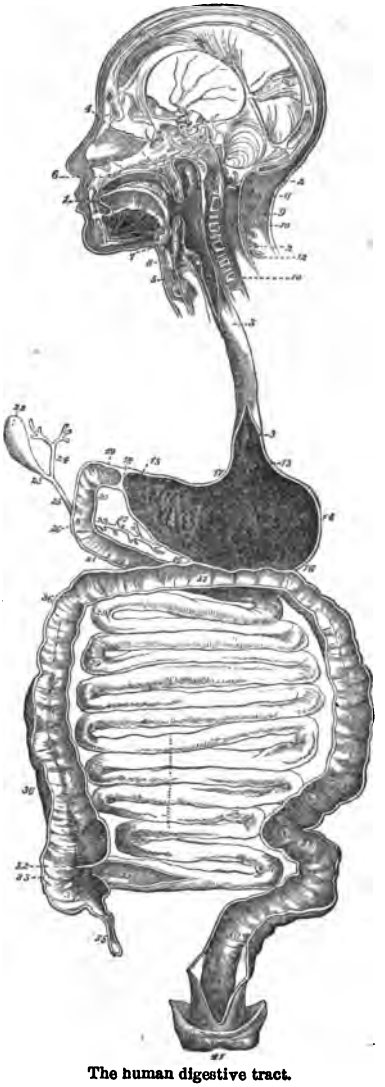
CONSTRUCTION OF THE DIGESTIVE APPARATUS IN MAN.

The digestive tract may be considered as presenting six prominent regions—the mouth, the pharynx, the œsophagus, the stomach, the small intestine, the large intestine. Their relative position and subdivisions are illustrated in Figure 1.—1, the tongue; 2, 2, the pharynx; 3, 3, the œsophagus; 4, the velum pendulum palati; 5, section of the larynx; 6, the palate; 7, the epiglottis; 8, the thyroid cartilage; 9, the medulla spinalis; 10, 10, bodies of vertebræ; 11, 12, spinous processes of

To what operation must the food be submitted before it can be absorbed? Into how many regions may the digestive tract be divided? Describe Figure 1.

ditto; 13, cardiac orifice of stomach; 14, splenic extremity; 15, pyloric extremity; 16, 16, greater curvature; 17, the less curvature; 18, pylorus; 19, superior transverse portion of duodenum; 20, middle or perpendicular portion; 21, inferior transverse portion; 22, gall-bladder; 23, cystic duct; 24, hepatic duct; 25, ductus communis choledochus; 26, its aperture in the duodenum; 27, duct of the pancreas, emptying into the duodenum near to the place of entry of the ductus communis choledochus; 28, commencement of jejunum; 29, 29, 29, jejunum; 30, 30, 30, ileum; 31, ileum opening into great intestine; 32, ileocolic valve; 33, ileocæcal valve; 34, cæcum; 35, appendix vermiformis; 36, 36, the ascending colon; 37, transverse arch of colon; 38, descending colon; 39, sigmoid flexure; 40, rectum; 41, anus.

Fig. 1.



The human digestive tract.

MECHANICAL ACTION OF THE MOUTH.

In the mouth the food is submitted to a twofold preparation. It is divided by the mechanical action of the teeth, and also simultaneously mingled with liquids secreted from the salivary glands.

In man the number of *temporary* teeth is twenty, ten in each jaw. They are arranged in three classes—four incisors, two canines, and four molars for the upper and lower jaw respectively. The *permanent* teeth, eventually substituted for these temporary ones, are thirty-two in number, classified for each jaw as four incisors, two canines, four bicuspids, and six molars. Their arrangement is exemplified in *Fig.* 2, representing the lower jaw, in which *i* is the middle and lateral incisor, *c* the canine, *b* the two bicuspids, and *m* the three molars.

Fig. 2.



The human lower jaw.

The movements of the teeth, aided by those of the tongue, accomplish a due abrasion of the food, and simultaneously incorporate it with the saliva. This is, therefore, a purely mechanical operation. It is analogous to the methods resorted to by chemists in their laboratories when they prepare solid materials for exposure to reagents.

INSALIVATION. PREPARATION AND USES OF SALIVA.

Three pairs of glands, the parotid, submaxillary, and sublingual, secrete saliva. Of these organs the parotid is the largest; its secretion is delivered through the duct of Steno. The submaxillary duct is Wharton's, but the sublingual pours its fluid through many small apertures. Besides these proper salivas, the lining

To what preparation is the food submitted in the mouth? What is the number of temporary teeth in man? Into what classes are they divided? What do the teeth accomplish besides the abrasion of the food? How many glands prepare saliva?

membrane of the mouth yields a fluid, the buccal mucus.

The *parotid saliva* is thin and watery, limpid and colorless, inodorous and tasteless. Secreted during fasting, or under the use of stimulating food, it is denser. It contains so large a quantity of lime that, on exposure to the air, it becomes covered with an incrustation of the carbonate of that substance. It also contains sulphocyanide of potassium. Its organic ingredient, if not albuminate of soda, closely resembles that body.

From the chemical constitution of the saliva of the parotids, the physiological function of those glands, as water-supplying organs, is established. They yield a certain quantity of watery juice, which, by reason of its thinness or fluidity, is readily incorporated with the food by the teeth. Parotid saliva appears to have no power of transmuting starch into sugar.

The *submaxillary saliva* is also colorless and limpid, tasteless and inodorous. It is lighter than the parotid, less alkaline, and contains less lime. For this reason, when exposed to the air, it does not become incrusted with carbonate of that earth. It contains sulphocyanide of potassium. It is so viscid and glutinous that it may be drawn into threads. From this physical property it probably facilitates deglutition by furnishing a kind of anti-friction coating.

The *sublingual saliva* is thin and watery, containing, like the parotid, but a small percentage of solid matter, and probably discharging a similar function.

Besides the special salivary juices, the lining membrane of the mouth pours forth a liquid — the buccal mucus—a thick and tenacious substance. It is alkaline in its reaction, does not coagulate on heating, its insoluble salts containing no carbonate of lime. It has been obtained for examination by tying the ducts of Steno and Wharton, keeping the nostrils open and the head inclined, so that, the animal being unable to swallow, the mucus flows out of the mouth.

The buccal mucus, if mixed with parotid saliva, does not appear to possess the power of turning starch into

What are the properties of parotid saliva? What are those of the submaxillary? What are those of the sublingual? What are those of buccal mucus? How do these juices respectively act on starch?

sugar, but, if mixed with the submaxillary secretion, it accomplishes that transmutation with facility.

The saliva, as obtained from the mouth, is therefore a mixture of the secretions of the various salivary glands. It is an alkaline juice, of a bluish color or colorless, in consistency glairy, readily frothing, and therefore well adapted for entrapping atmospheric air. It contains, of solid matter, from 0.348 to 0.841 per cent. Its alkali appears, for the most part, to be combined with an organic substance, ptyaline.

On standing, saliva separates into two layers; a transparent one, which is supernatant, and a grayish turbid one below. Its chemical reaction varies to some extent with the state of the system; thus, after long-continued fasting, from being alkaline, it may approach the neutral state.

The specific gravity of mixed saliva varies from 1.004 to 1.009. These variations depend on many different causes, there being a diminution after the taking of drink, and a greater increase after taking food, than even is observed in the fasting state. An animal diet especially increases it.

Under ordinary circumstances, the saliva is secreted to an amount of from 15 to 20 ounces daily. The exudation is more copious during mastication, speaking, reading, more being produced by the use of hard than soft food. Mental emotions exert a control over its flow, sometimes diminishing it, as in moments of anxiety, sometimes increasing it, as by the anticipation of food. After eating, the flow continues to a considerable extent; it is also provoked by the use of aromatics. On irritation of the interior of the stomach through a gastric fistula, the flow is simultaneous with that of the gastric juice.

The movements of the jaw and the pressure of the food give rise to variations in the quantity of saliva. It is perhaps for these reasons that the parotid gland on that side of the mouth which is most used in mastication secretes more than the other. Of the proportion

What are the properties of mixed saliva? What is ptyaline? How much saliva is secreted in a day? What circumstances exert a control over its flow? Do both the parotids commonly secrete the same amount?

of the different kinds of saliva in the mixed secretion, nothing is known with certainty in the case of man, but it is said that in horses the parotids furnish two thirds, the submaxillaries one twentieth, and the sublinguals and mucous follicles the rest. The secretion of the saliva goes on during sleep.

Constitution of Saliva.

Water	994.10
Epithelium and mucus	2.13
Fat	.07
Ptyaline and alcohol extract	1.41
Sulphocyanide of potassium	.10
Fixed salts	2.19
	1000.00

Of the fixed salts the chief are, the phosphates of soda, lime, and magnesia, and the chlorides of sodium and potassium. The sulphocyanide of potassium varies in amount considerably: it increases after meals, and especially after the use of condiments, salt, pepper, spices. Those articles which contain sulphur, as mustard, garlic, radishes, increase its amount in a very marked manner.

Not only does the saliva, as derived from the different glands, present differences of constitution; it likewise differs in various animals, and in the same animal according to its age. This is observed even in the case of man. The saliva of an infant at the breast possesses very little power of saccharizing starch, a transmutation which that of the adult accomplishes with energy.

The action of this secretion appears to be limited to starch, and certain kinds of sugar, which first yield lactic and then butyric acid. It does not exert any influence in transforming albuminous matter.

The saliva discharges many functions. It acts as an anti-friction coating to the food descending into the stomach. It is a necessary intermedium in the sense of taste, for substances to be sapid must be more or less soluble in this juice. If insoluble, they are tasteless. It also moistens the interior of the mouth, and prevents

What proportion is furnished by each of the glands respectively? What are the chief fixed salts of the saliva? What substances increase the amount of sulphocyanide? What is the effect of infant and adult saliva on starch? Describe the general functions of saliva.

the sensation of dryness. But its chief duty seems to be that of promoting the digestive operation; for, though the food remains in the mouth but a short time, the action of the saliva is prolonged after the masticated mass has been deposited in the stomach. Though the direct admixture of saliva with gastric juice injures the power of the latter, this effect does not ensue in the stomach, since they act for the most part separately. The action of the gastric juice is superficial, and two distinct operations are therefore conducted at the same moment, the surface of the food changing under the influence of the gastric juice, and the inner portion under that of the saliva. I believe that in this manner the salivary juice lends itself to stomach digestion, for by its aid starch changes into grape sugar, and the transmutation does not stop at that point, but goes on to the production of lactic acid. An acid juice is essential to stomach digestion.

It has been suggested that the eventual arrest of the action of saliva on reaching the stomach may be due to the digestion of its ptyaline by the gastric juice.

The double digestion, partly salivary and partly gastric, occurring in the stomach, is doubtless one of the causes of those differences noticed between the natural action of that organ and the artificial imitations of it. The influence of the saliva, even under these, which may seem at first sight to be unfavorable circumstances, is far from being trivial, an effect well illustrated by the instantaneous manner in which a solution of starch in water, mixed with an equal quantity of saliva and agitated, is transmuted into a solution of sugar. In a few moments its viscidity is lost, it fails to give the blue reaction with iodine, becomes sweet to the taste, and readily answers to Trommer's test.

Besides the duties mentioned, the saliva incidentally accomplishes a secondary object by its power of retaining gases in its froth or foam. Atmospheric oxygen by this means is incorporated with the food during mastication, and is thus enabled to exert an important influ-

In what manner is salivary digestion continued in the stomach? In what manner is it possible that salivary digestion is arrested in the stomach? How may the influence of saliva on starch be tested? What is the use of the air carried by insalivation into the stomach?

ence in promoting the action of the gastric juice. For to the inception of the change which that juice impresses on the food, oxygen is necessary. It is brought into the cavity of the stomach entangled or dissolved in the saliva.

It has just been mentioned that the action of saliva on starch is not restricted to the production of sugar, but that it may end in the formation of lactic acid. If, therefore, any thing intervenes to check the supply of hydrochloric acid, which usually gives acidity to the gastric juice, the system possesses within itself the means of compensating for the difficulty. In the interior of the digesting mass lactic acid is being set free. This acid, as has long been known, can replace hydrochloric acid in its physiological duty.

Since fishes and water animals generally have no salivary glands, or only rudimentary ones, some physiologists have inferred that the use of the saliva is for the commingling of the food with a due portion of water. This would reduce the importance of insalivation very greatly, and, indeed, is scarcely consistent with the elaborate mechanism of ruminant animals. It is worthy of remark that, even among fishes, there are some which exhibit a true rumination, as, for example, the carp. This is not alone for the purpose of resubmitting the food to the abrading action of the pharyngeal teeth, but likewise for commingling it with the secretion of the pharyngeal cavity.

Among the functions of the saliva we ought not to overlook the influence its rapid secretion must exert on the state of tension of the blood-vessels, an influence which probably favors the absorption going on in the stomach and intestines.

DIGESTION IN THE STOMACH.

Thus prepared by mastication and insalivation, the food descends into the stomach, passing along the pharynx, which dilates to receive it. The rima glottidis spontaneously closes, and additional security is given to

What acid may be eventually produced by the saliva from starch? For what purpose is it that certain fishes ruminate? How is the condition of the blood-vessels affected by the secretion of saliva? Describe the passage of the food through the œsophagus.

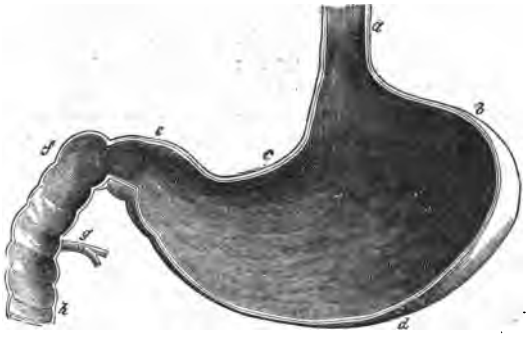
the respiratory passage by the valve-like shutting of the epiglottis. Through the œsophagus the morsel advances by the contraction of the muscular coat, with a wave-like or undulating motion onward. The food is now delivered at the cardiac orifice of the stomach, and, entering that organ, is submitted to the gastric juice exuding from the mucous membrane.

The stomach is an expansion of the alimentary canal between the œsophagus and the duodenum, of a conical figure, the base to the left. It communicates with the œsophagus by its cardiac orifice, and by its pyloric with the duodenum. It consists of three coats or tunics—the serous or peritoneal, which is exterior; the muscular, which is intermediate; and the mucous, which is interior. They are connected with each other by cellular tissue. The fibres of the muscular coat run in three different directions, constituting three layers; the superficial ones are longitudinal, radiating from the œsophagus over the surface of the organ; those of the middle layer are circular, or ring-like; they are well developed about the middle of the stomach, and by their contractions sometimes make it assume a divided appearance, as though composed of two compartments. Toward the pylorus they are also greatly re-enforced. The fibres of the third layer take, for the most part, an oblique direction. The interior or mucous coat is sometimes termed the villous, from its velvety appearance. Its color is very variable; it is folded into rugæ, admitting of variations in the distention of the stomach, without interference with the structure or functions of the membranes of which they are a part. The cardiac orifice is plicated, and the opening into the duodenum is through a circular fold with a central aperture—the pyloric valve, which being surrounded with a band of muscular fibres acting as a sphincter, the passage from the stomach to the intestine may be entirely obstructed.

The stomach is seen in section *Fig.* 3, *a* being the œsophagus; *b*, the greater extremity; *c*, the smaller curvature; *d*, the great curvature; *e*, the pyloric or less end; *f*, *h*, the duodenum; *g*, place of entry of the duc-

What is the general shape of the stomach? How many coats has it? Describe each of them. Describe the parts shown in *Fig.* 3.

Fig. 3.



Section of the human stomach showing its mucous interior.

tus communis choledochus and pancreatic duct. The place of junction of the œsophagus is the cardiac region: the membrane is there plicated. The place of junction of the duodenum is the pyloric region.

The typical form of the digestive apparatus is a sac with one aperture, serving the double purpose of affording an entrance to nutritive material, and an outlet to undigested remains. In a higher condition it may be conceived of as a tube open at both ends, and having a sac-like swelling on its middle part. The portion of the tube anterior to the sac is the type of the œsophagus, its aperture answering to the mouth, the sac-like swelling being the type of the stomach, and the tube leading from it representing the intestinal canal. In the more elementary of such forms, vessels arise from the walls of the digestive cavity, and pass to all other parts of the system. These serve to convey the elaborated material. Certain appendages are soon to be discovered in connection with this simple digestive mechanism. They are for the preparation of salivary, gastric, pancreatic, or biliary juices. In size or development they vary with the habits of life of the animal, or with the nature of its food. Indeed, the same remark may be made as respects the entire digestive tract

What is the typical form of the digestive apparatus? How does it gradually become more complex? What appendages to it are gradually provided?

of the highest tribes. Thus, in the bat, the length of the intestine is to that of the body as three to one, but in the sheep as twenty-eight to one. The ruminants generally have an intestinal tube of great length. In man and in monkeys the proportion is about five or six to one. Again, as regards construction, there are many diversities, the number of digestive dilatations and their size corresponding in some measure to the nature of the food.

The interior of the stomach is of a light pink color, its velvety surface being coated over with mucus. On the introduction of food or any irritant, lucid points protrude from the mucous coat; these are the mouths of the follicles from which the gastric juice exudes. When in activity, the temperature of the interior of the organ is about 100° Fahr.

The *gastric juice* is a viscid fluid, with an acid reaction and faint odor. After filtration through paper it is clear and transparent, and possesses all its physiological qualities. The impurities thus separated from it are merely old undigested residues, on which, in no respect, its qualities depend. It does not become turbid at 212°, remains long undecomposed, and retains its digestive power even after it has become mouldy. It does not accumulate in the stomach while fasting, but requires a stimulus for its ejection, and even then is produced in a limited quantity only. It is secreted by the follicles of the mucous membrane of the stomach. They are cup-shaped cavities, about the two hundredth of an inch in diameter, from the bottom of which project two or more parallel tubes, the mouth of the cup opening into the stomach, and the tubes ending in a closed termination in the tissue beneath. Toward the pylorus the cups become deeper, so as to assume the form of a cylinder, and the projecting tubes are shorter. Between these follicles blood-vessels pass.

Nearly two thirds of the solid material of the gastric juice is pepsin. Exposure to a very low temperature does not deteriorate the properties of this substance,

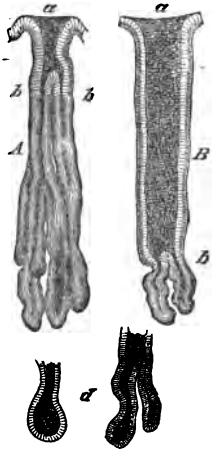
What is the appearance of the interior of the stomach? What is its temperature? Describe the gastric juice. How is it secreted? In what manner are the blood-vessels related to the follicles? What are its properties?

for it will resume its activity even after being frozen. But, on the contrary, a temperature approaching ebullition destroys its solvent power, and the same effect ensues when it is neutralized by an alkali.

The digestive power of this juice is impeded by the presence of almost any alkaline salt. It is owing to its alkalinity that saliva injures the digesting power of gastric juice. On the contrary, that power is very much increased by the presence of fat, which promotes the conversion of protein bodies into peptones.

In *Fig.* 4 is a representation of stomach follicles and their tubes in a vertical section. The specimen is from the dog after twelve hours' fasting. *A* represents these structures in the middle region of the stomach; *B* in the pyloric region; *a a*, orifices of the follicles on the inner surface of the stomach; *b b*, different depths at which the columnar epithelium is exchanged for glandular; *d*, pyloric tubes terminating variously, and lined to their extremities with columnar epithelium.

Fig. 4.



Vertical section of stomach follicles and tubes magnified 150 diameters.

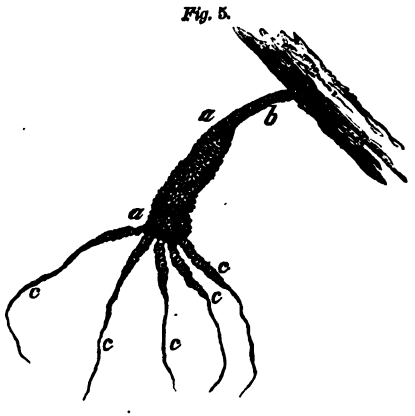
There are therefore two distinct classes of stomach follicles, differing from each other in anatomical construction, and, as there is now reason to believe, also in physiological function. It is suspected that the acid of the gastric juice is prepared by one class of these structures, and the pepsin by the other.

Though we have spoken of the follicles as excavations or cup-like depressions in the mucous tissue, according to the description usually given of them by anatomists, it is to be understood that this view of their construction is philosophically incorrect, for each, instead of be-

What is the effect of an alkaline salt on it? What is the effect of fat? Describe the stomach follicles shown in *Fig.* 4. How many classes of stomach follicles are there? What are their supposed functions? In what respect is the construction of the stomach hydroid?

ing a mere excavation, is truly a distinct organism, analogous in structure and many of its functions to a polype. The hydra, a fresh-water polype, may be taken as the type of this organism. This animal, *Fig.* 5, consists of a bag or digestive sac, *a a*, ending in a cylinder, *b*, the opening to which is furnished with numerous tentacles, *c c c*; the tentacles enfold in their grasp objects on which the hydra feeds, and by their contractions carry them to the sac. Into the interior of the sac a juice exudes possessing digestive powers, and soon dissolving food.

Fig. 5.



We may therefore regard the follicular structure of the stomach as a colony of polypes, the tentacles of which are converged into a muscular tube, constituting the œsophagus. In a stomach of ordinary size there are probably a million of these organisms. Digestion is undoubtedly conducted on the same physical principles in both cases, though in the polype the food matter enters the follicular cavity of which the body of the animal consists, but in man is contained in the stomach, into which the follicles open, and pour forth their digestive fluid.

With respect to the acid constituent of the gastric juice, it is hydrochloric or lactic. The latter has probably originated in the manner just described by the action of the saliva on starch; the former undoubtedly comes from the common salt ingested. Perhaps, under a deficiency of common salt, lactic acid discharges the

Describe *Fig.* 5. What is the œsophagus? What is the acid constituent of the gastric juice?

entire duty. About twenty parts of gastric juice are required to digest one part of dry albumen, and about 70 ounces are secreted in a day. If the hourly destruction of fibrin in average muscular action is 62 grains, about 60 ounces of gastric juice would be required each day for muscular repair. A very large demand is therefore made upon the water in the system for this use. But here the same remark occurs as in the case of the saliva; the water, after accomplishing its object, is not lost to the economy, but is immediately reabsorbed.

On the deposit of the food in the stomach, a movement of translation is given to it by the alternate contraction and relaxation of the fibres of the muscular coat, aided to a considerable extent by the respiratory movements of the abdominal walls. The course of this rotation commonly is, that after passing the cardiac orifice the food moves from right to left round the great extremity, and then along the large curvature from left to right, returning along the small curvature, and occupying from one to three minutes to perform this revolution, the motion continuing for a few minutes at a time.

While this is going forward digestion is rapidly taking place, and the portions that have suffered complete action are oozing through the pyloric valve into the intestine as a semi-fluid and apparently homogeneous material called chyme. This process has fairly set in in the course of an hour, and is usually finished in about four. In consistency, color, and chemical reaction, the chyme varies with the nature of the food, its chemical constitution, and its quantity.

EXPLANATION OF GASTRIC DIGESTION.

Such is the general description of the act of digestion. We have next to enter on a physical examination of what it is that really takes place in the stomach. It was formerly supposed that digestion is entirely due to nervous agency, since, if the pneumogastric nerves be

How much of that juice is provided each day? What is the hourly destruction of fibrin? Describe the movements the food undergoes in the stomach. How long does each rotation require? Describe the appearance and formation of chyme. Through what valve does the chyme pass? Do the nerves exert any influence in digestion?

divided, the process is very much interfered with. But this interference takes place only in an indirect way, for the division of those nerves is attended with such a paralysis of the stomach that those movements which so well serve to mix up the food with the gastric juice, and expel it through the pyloric valve, are put an end to.

The acidulating material of the gastric juice is hydrochloric acid. Is it possible by artificial mixtures containing that substance to reduce food articles to a digested condition? This inquiry introduces a description of the experimental investigations which have been made in artificial digestion.

When water acidulated with hydrochloric acid is kept in contact with albumen, no action is perceptible at ordinary temperatures in a moderate period of time. If the temperature is raised to about 150° a slow dissolution ensues, which becomes better marked as the heat rises toward 212°.

But if to the weak hydrochloric acid thus made to act on albumen, pepsin is added, the solution takes place with rapidity at moderate temperatures. An ounce of water, mixed with twelve drops of hydrochloric acid to which one grain of pepsin has been added, will completely dissolve the white of an egg in two hours at a temperature of 100°. It acts in the same manner on cheese or flesh, these nitrogenized articles being converted into soluble non-coagulable bodies. The acid does not enter into chemical combination with the dissolving organic matter. It may be recovered from the solution by resorting to proper processes.

Pepsin—the substance resorted to in these experiments—may be obtained by macerating the mucous membrane of the stomach for a short time in lukewarm water. This water, along with a part of the pepsin, removes various impurities; it may therefore be cast away; the maceration being then continued with a fresh portion of cold water, and this being submitted to filtration, and subsequently evaporated at a low temperature to dryness, yields the pepsin as a gummy mass.

In artificial digestion, what is the action of hydrochloric acid? What occurs on the addition of pepsin? Describe the preparation of that body.

Its analysis indicates that pepsin contains less carbon and more nitrogen than the members of the so-called protein group.

A weak acid therefore possesses at a high temperature the power of bringing into a state of solution the various nitrogenized food matters, and at lower degrees fails of that property; but in the presence of pepsin the solvent powers are assumed under the latter circumstances, and therefore it is said of this substance that it replaces a high temperature. By its aid, hydrochloric or lactic acids present in the stomach reduce the food to a uniform pulpy mass—the chyme.

Formerly it was supposed that the act of digestion was simply mechanical, the food being ground down to chyme by the motions of the stomach. Reaumur's experiments showed the error of this supposition. He took small hollow silver balls, perforated with holes, and, having filled them with meat, caused them to be swallowed by a dog. When they had remained in the animal's stomach a suitable length of time, they were withdrawn by a thread previously attached to them. Now if the stomach acted by a triturating or grinding power, the material within the ball would be entirely protected, but if by a solvent power exerted by the gastric juice, the digestion should at most be only delayed. Accordingly it was found that this was what actually took place, digestion being fully, though more slowly accomplished, the action commencing on the outside of the material, and gradually reaching its centre. If the balls were kept in the stomach long enough, they came out quite empty at last.

The idea that some mysterious change is impressed upon the food by the vitality of the stomach may therefore be abandoned. It does not appear that there is any essential difference between natural digestion and the artificial imitation of it, either as respects the order of action or the final result. Moreover, the anatomical consideration that the food is yet outside the body, though it is inside the stomach, should be sufficient to

How does it stand related to the protein group? In what manner may it be said to replace a high temperature? Describe the experiments of Reaumur. What is the final object of digestion? Does the food acquire any vital properties in the stomach?

remove all errors of that kind. A living surface, such as the skin, never exerts any chemical action at a distance; and the lining membrane of the stomach, both as regards its physiological origin and its anatomical relation, is nothing more than a reflected continuation of the skin. The act of digestion is completed long before the nutrient material is absorbed and thrown into the torrent of the circulation. But then, and not till then, is the food fairly in the interior of the body.

Digestion is not, therefore, to vitalize the food, as the ancients supposed, nor to communicate to it any new or obscure properties; it is for the purpose of comminuting, subdividing, dissolving, or bringing it into that minutely suspended state that it can without difficulty be absorbed by the lacteals and veins. There is a complete analogy between this operation and the artificial processes to which the chemist resorts in his laboratory for the solution of various bodies. He, too, uses mechanical implements—the mortar and pestle to grind, the hammer to crush, the rasp to abrade. When these have carried the subdivision sufficiently far, he resorts to acids or other solvents, and thus breaks down the compactness of the hardest minerals, and brings them into the dissolved state. The animal world presents us with a thousand illustrations of the principles here set forth, mechanical contrivances curiously arranged. For instance, birds, whose plan of organization is such as to meet the case of locomotion through the air, could not have the anterior part of their bodies loaded with teeth, accompanied as they must have been with a powerful muscular apparatus. Such a mechanism would have rendered the animal top-heavy, and have been totally inconsistent with flying. But, to avoid this difficulty, that which might truly be regarded as the mouth is lodged in the interior of the body, nearer the centre of gravity. It is the gizzard. Instinct teaches the bird to swallow small angular stones; they serve as temporary teeth, and the food, rasped between powerful muscular surfaces, is soon brought into a fit condition for the action of the stomach. The chemist, too, puts fragments of glass or of quartz into the mortar in which he

Is it illustrated by any artificial operations? What is the function of the gizzard of birds?

is conducting the reduction of a tough or resisting substance.

The first object of digestion is, therefore, the subdivision of the food. The operation begins in the mouth by a resort to mechanical implements, and when these have carried the process as far as they can, the stomach continues the duty. In its cavity, when in full activity, the temperature is 100°; a periodically increasing and relaxing motion of revolution is kept up, gastric juice exudes in definite quantity, the hydrochloric and lactic acids exert their action, and in the course of three or four hours a complete reduction is accomplished.

Allusion has been made to the probability that different portions of the mucous membrane of the stomach discharge functions wholly distinct, one portion being devoted to the elaboration of pepsin, another to the secretion of hydrochloric acid, another to the preparation of a special mucus. This view derives considerable support from many facts in comparative physiology. In those cases in which the food approaches, in its mechanical and chemical condition, to the form which it is destined to assume as a part of the body of the animal receiving it, the stomach is simple in construction, and is little more than a mere dilatation of the alimentary canal. But when, as among the herbivora and granivora, there is a great difference between the form of the food received and the form of the tissues to be made, the digestive sac no longer presents such a simple structure, but is parted off into distinct regions, or is actually converted into distinct organs.

Fig. 6.



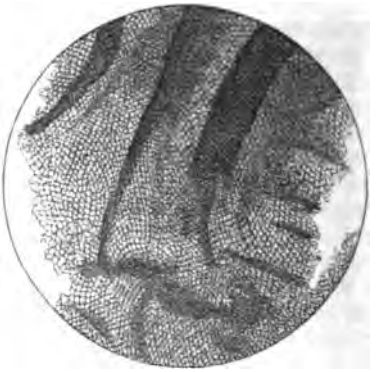
Digestive tract of a carnivorous beetle.

Thus, in the insect digestive tract shown in *Fig.* 6, *a* is the pharynx, *b* the œsophagus, leading into a crop or insalivatory pouch, *c*, and this into the gizzard, *d*, the function of which is to

Give a summary of the operation of the stomach. Does the entire interior surface of the stomach discharge one function? Describe the regions indicated in *Fig.* 6.

rasp up and abrade the more resisting portions of the food, which, when this is accomplished, passes into the true stomach, *e*, and from thence into the intestine, *g*. The delicate vessels about *f* are supposed to be biliary tubes, and *h* glandular secreting organs.

Fig. 7.



Mucous membrane of the stomach of a carnivorous beetle magnified 50 diameters.

Even in these cases of minute organization, the mucous structure remains the same as in larger animals of the same mode of life. The photographic representation in *Fig.* 7 displays the same reticulated appearance in the stomach of the carnivorous beetle as described in the case of man; and undoubtedly, with similarity of structure there is similarity in the manner of action.

Fig. 8.



Digestive tract of the common fowl.

A regional division of the digestive apparatus is also presented in the case of many birds, as is shown in the photographic representation, *Fig.* 8, in which we have the digestive tract of the common fowl, *a* being the œsophagus leading into the insalivating pouch or crop, *b*, which empties into the stomach, *c*, and this into the gizzard, *d*. In the stomach, which is relatively small, the digesting ma-

What are the regional divisions in the digestive tract of a common fowl?

terial is mingled with the gastric juice before being submitted to the action of the gizzard. From the gizzard it is passed into the small intestine *f*, *f*. In the figure, *e* is the liver, *g*, *g*, the cæca, and *h* the cloaca.

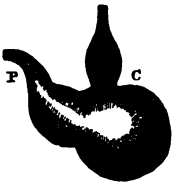
In the ostrich, as shown in *Fig.* 9, the local distribution of the glandulæ very obviously marks out a regional distribution of function. C is the cardiac cavity, the mucous membrane of which is studded here and there with glands; G G are the surfaces of the gizzard. Among the higher quadrupeds, the evidences of a similar division of function are presented. Thus, in the dormouse, *Fig.* 10, there are two compartments: a cardiac, C, and a pyloric, P; the same being exhibited more perfectly in the Cape hyrax, *Fig.* 11. In these cases the cardiac

Fig. 9.



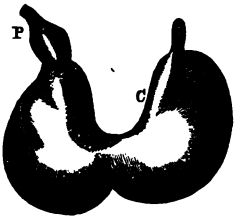
Interior of stomach of African ostrich.

Fig. 10.



Stomach of dormouse.

Fig. 11.



Stomach of Cape hyrax.

compartment is often lined with cuticle, but the pyloric not. An increase in the number of these cavities occurs as the food becomes more heterogeneous. In the porcupine, *Fig.* 12, there are four, and in the porpoise, *Fig.* 13, five.

What principle is illustrated by the Figures from 9 to 14 inclusive?

Fig. 12.



Stomach of porcupine.

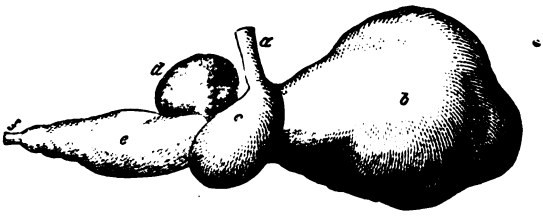
Fig. 13.



Stomach of porpoise.

The case of ruminants possesses a special interest. In these there are what might be termed four different digestive chambers, as is shown in *Fig.* 14, in which *a* is

Fig. 14.



Digestive cavities of a ruminant.

the œsophagus; *b*, the ingluvies or paunch; *c*, the reticulum or honey-comb stomach; *d*, the omasum, manyplies, or third stomach; *e*, abomasum, reed, or fourth stomach; and *f*, the pylorus. The food, roughly triturated in the mouth, enters the ingluvies, in which it is moistened; it then passes into the honey-comb or second stomach, which likewise receives directly the water that has been taken, and, after it has been thoroughly moistened therewith, it is returned to the mouth in small quantities, to undergo a more complete mastication and insalivation. Being swallowed again, it is now directed into the third stomach, from which it passes into the fourth. In this it is submitted to a true acid digestion, a gastric juice being secreted from the walls of this cavity. It is the mucous lining of this cavity which yields rennet. That

In ruminating animals how many digestive chambers are there? What are the several uses of those divisions? Which is the cavity that yields rennet?

these complicated motions and these successive actions of the different cavities are for the purpose of preparation for the true digestion of the fourth stomach, is clearly proved by the fact that in the calf the milk passes directly into the abomasum.

In view of the preceding facts, it may be concluded that, so far from there being any thing in contradiction to the doctrine that different portions of the digestive surface of the mucous membrane of the stomach are devoted to different duties, there is strong evidence in support of its truth, derived partly from the instances furnished by comparative anatomy, and partly from the anatomical structure of the gastric mucous membrane. The four separate digesting chambers of the ruminating herbivora are merely an elaboration of the structure presented by an apparently homogeneous mucous surface in man.

The gastric juice not only dissolves, but also, in an incipient and indirect manner, modifies the food. Protein bodies and gelatinous matters yield substances after its action of the same composition as their own, but with different physical and chemical properties, being readily soluble in water, and even in diluted alcohol, and not forming insoluble compounds with metalline salts. These substances have been designated as peptones; and since they may arise without the evolution or absorption of any gas, and the quantity of sulphur they contain is the same as that in the bodies from which they were derived, the action appears to be really an assimilation of water, the other ingredients remaining unchanged.

It is interesting to observe the economical manner in which the hydrochloric acid element of the gastric juice is managed. To the proper understanding of this, it is necessary to anticipate what will have to be more fully considered in describing the bile, a uniform ingredient of which is the oxide of sodium, or soda. The hydrochloric acid of the gastric juice and the soda of the bile are derived from the same source—common salt, which is either present in the food, or purposely added as a

Is there reason to suppose that regional divisions exist in the human stomach? What are peptones? How is common salt used in digestion?

condiment. Salt undergoes decomposition easily, yielding the two products specified, that is, hydrochloric acid and soda, and is readily formed by the reunion of these substances.

There exists in the action of the kidneys a special provision for preventing the quantity of chloride of sodium present in the blood from rising over 41 parts in 10,000. This, of course, controls the amount diffused through the tissues. The necessity of such a regulation becomes apparent when we consider that the rate of the solubility of albumen and casein in water is governed by the presence of that substance, as is also the quickness with which the coagulation of fibrin takes place, and the repair of the waste of the muscles.

Common salt introduced into the system undergoes decomposition, furnishing hydrochloric acid to the gastric juice, and soda to the bile. Considering the large quantity of these secretions produced in a short space of time, it is clear that the drain of common salt must be great—not less than a third of an ounce a day; yet the quantities consumed, at most, are only small.

How, then, is this to be explained? There is no other source from which these bodies can come than the one indicated—the common salt, and yet it seems to be totally inadequate.

This difficulty is rather imaginary than real. Things are so arranged that a limited quantity of salt can produce unlimited quantities of gastric juice and bile; for the former, associated with the food it has digested, scarcely escapes from the pyloric valve before it encounters the bile and pancreatic juices discharging into the duodenum, and through the length of the upper portion of the small intestines, these secretions, together with the food they have acted upon, are brought into complete contact. The reproduction of chloride of sodium is therefore constantly taking place in intestinal digestion, and it returns back to the system through the absorbents. Again it undergoes decomposition, its acid reappearing in the gastric juice, and its alkali in the pancreatic juice and bile. By thus using a small amount

How much of it may exist in the blood? What substances does it yield by decomposition? In what way may a limited quantity of it be sufficient?

over and over again, great effects can be produced, and it is then only necessary to restore those small portions that are wasted in carrying out the general scheme.

In the low-pressure marine steam-engine we have an example of the same kind. A certain quantity of water is vaporized in the boiler and condensed in the engine; pumped back into the boiler to be vaporized, and then recondensed in the engine. Comparatively little is required to supply the wants of the machine, and long voyages can be made with only as much water as will compensate for the necessary waste arising in the working.

For the sake of presenting the consideration of the function of digestion with clearness, it is customary to leave out of consideration the subordinate actions taking place both in the stomach and intestine. This, however, involves a certain amount of error, since respiratory or non-nitrogenized digestion occurs in the former cavity, and nutritive or nitrogenized in the latter. Nevertheless, there can be no doubt that if our view is restricted to the more imposing characters, we are justified in accepting the dogma that "stomach digestion is histogenetic or nitrogenized, and intestinal digestion is calorifacient."

Under the most comprehensive point of view, examining the action of the entire digestive tract from the mouth to the rectum, we discover a recurrent periodicity. In the mouth, the transitory digestion taking place is wholly expended upon the calorifacient food; in the stomach it is the nutritive portion which is chiefly attacked; in the duodenum there is a return to the calorifacient, and in the cæcum of animals a resumption of the nutritive. This last is less apparent in man, for in him the cæcum exists only in a rudimentary state, represented by the appendix vermiformis.

Intermediate between the classes of calorifacient and histogenetic food, belonging, by its composition and conditions of digestion, to the latter, but by the function it discharges to the former, is gelatine, a nitrogenized substance. It appears to be always derived from albu-

How is this illustrated by the steam-engine? What is meant by the recurrent periodicity of digestion? In what manner does the cæcum exist in man?

men, and any portion which may have been received in the food is never directly assimilated or used for the fabrication of tissue, but solely ministers to the production of heat. Though thus a calorifacient body, its place of digestion is the stomach. After it has suffered the action of that organ it has lost its power of gelatinizing, can no longer be precipitated by chlorine, nor give the leather precipitate with tannin. The use of it under the form of jellies, soups, etc., is always attended with the appearance of an unusual quantity of urea, and hence the administration of those domestic preparations, under an idea of their great nutritive value, is to be looked upon as only a popular error. In an indirect way, however, under the conditions of restricted diet, usually met with in the sick-room, gelatine doubtless maintains an interesting relation to the albuminoid bodies in this, that it protects them from destruction by undergoing oxidation itself, and so satisfying the requirements of the respiratory mechanism; for, were there not such a substance present to receive the attack, the respired oxygen would rapidly bring on the waste of the proper nitrogenized tissues.

Statements respecting the digestibility of different articles of food must be received with many restrictions. If, as the earlier physiologists believed, the stomach was the sole digestive cavity, and the intestine only for the purpose of absorption, they would doubtless be much nearer to the truth. But when we recall that the digestion of fats does not even begin until the intestine is reached, and that the digestion of the nitrogenized substances is only in part accomplished by the gastric juice, but goes on under the influence of the intestinal juice throughout the whole length of the small intestine, we see at once how imperfect and even incorrect are the indications afforded by such experiments as those of Spallanzani, who introduced food articles into the stomach through the œsophagus in perforated silver vessels, or those of Beaumont, who availed himself of a gastric fistula. Neither can we take, in all instances, the time

What may be observed respecting the digestion of gelatine? What uses does gelatine really subserve? What circumstances interfere with estimates of digestibility? What experiments were made by Spallanzani?

which an article of food will remain in the stomach as a measure of its digestibility, for this is known to vary with many conditions, as, for instance, the quantity introduced at a time, and the condition of the organ itself. The white of an egg, representing soluble albumen, if introduced into the stomach of a fasting dog through a gastric fistula, will disappear in less than an hour; but if the whites of eight eggs be introduced, portions thereof can be recognized after four hours.

So far as such examinations go, they do not exhibit any marked difference between albumen, fibrin, and casein. Gelatine, however, is acted on with remarkable rapidity. The experiments which have been made on the digestibility of vegetable food introduced through gastric fistulæ are obviously of no use, since the chief constituents thereof, such as starch and fat, are not even influenced in those circumstances until they have reached the intestine. Their passage from the stomach in this unchanged state, or changed only so far as their nitrogenized ingredients are concerned, may teach us the important fact, which should in these inquiries be always borne in mind, that disappearance from the stomach is one thing and digestion another, and that even though a substance may have passed the pyloric valve, its digestion, far from having been completed, may not as yet have commenced.

The digestion of nutritive or nitrogenized material—histogenetic digestion—is therefore carried on in the stomach mainly; and though first mechanical, and then chemical agencies are resorted to, the object is throughout the same—to obtain the food in such a divided and changed state that it can pass, dissolved in water, into the capillary vessels.

How does the quantity of food affect these estimates? What food articles altogether escape digestion in the stomach? To what class of food is the action of that organ restricted

CHAPTER IV.

OF CALORIFACIENT OR INTESTINAL DIGESTION.

Nature of Intestinal Digestion.—Structure of the Intestine.—Digestive Fluids of the Intestine.—The Pancreatic Juice.—The Enteric Juice.—Juice of Lieberkuhn.—Secretion of Peyer's Glands.—Illustration of Intestinal Digestion from the making of Wine.—Making of Bread.—Influence of Heat over Ferments.—Comparison of Gastric and Intestinal Digestion.—Changes of the Intestinal Contents.—The Fœcal Residues.

After the chyme formed in the stomach has passed through the pyloric valve into the small intestine, the influence of the gastric juice continues for a certain time, even after the bile and pancreatic juices have been reached. Since their action must be necessarily, in the first instance, superficial, the interior of the mass is still undergoing stomach digestion.

But, setting aside this incidental result, which at the most can not be of long duration, the digestive operation taking place in the part of the intestinal tract now under consideration is upon the heat-making food.

The organ in which calorifacient digestion takes place may be described as a tube bounded by two valves, the pyloric above and the ileo-cæcal below. Its length may be estimated at about twenty feet. The digestive surface, making a due allowance for its increase by reason of its valvular structure presently to be described, can not be much under 3500 square inches. The dimensions of the calorifacient digesting surface are therefore far greater than those of the nutritive.

The interior and acting portion of this tube presents two different systems of apparatus, and is occupied in

Why is it that stomach digestion continues in the intestine? To which class of food is intestinal digestion, however, devoted? What is the length and surface of the intestinal tube? What two systems of apparatus does it contain?

the discharge of two totally distinct functions, digestion and absorption. It is, perhaps, this double duty which demands so extensive a surface, and not the necessities of heat-making digestion alone.

Like the stomach, this tube consists of three coats—a serous, a muscular, and a mucous. The latter is gathered up in its interior into numberless projecting folds—the valvulæ conniventes. These serve to increase the surface to which the food is exposed, and perhaps afford a mechanical obstacle to its passing too quickly forward. They tend also to break the continuous motion, and bring the interior parts of the chyme to the surface. The onward movement is of course due to the pressure exerted conjointly by the straight and circular fibres of the muscular coat. Anatomists divide the tube into three portions—the duodenum, jejunum, and ileum.

Soon after the chyme has escaped through the pyloric valve into the duodenum, it comes under the influence of the bile and pancreatic juices, sometimes discharged upon it at a common point, and sometimes at a little distance apart. Almost simultaneously it is submitted to the mechanical action of the valvulæ conniventes. As the intestine is distended, these project with a certain degree of turgidity, and accomplish their mechanical object.

But, besides the pancreatic and biliary fluids, there are other juices thrown upon the passing chyme—the enteric juice, coming from Brunner's glands, and a liquid oozing from the follicles of Lieberkuhn. Moreover, the organisms known as Peyer's glands are affecting the contents of the tube. Of each of these it is necessary therefore to speak.

1st. The *Pancreatic* juice, secreted by the pancreas, an organ bearing a resemblance in its anatomical construction to the salivary glands, and hence usually regarded as one of that group. The juice itself is analogous to saliva, being viscid, and in its reaction alkaline. It is said to contain no sulphocyanide nor any suspended particles. It acts upon starch even more energetic-

What are the valvulæ conniventes? What is their use? How do anatomists divide the intestinal tube? Mention the juices poured into it. From what glands does the enteric juice come? What are the properties of the pancreatic juice?

ally than saliva, transmuting it into sugar and lactic acid, and upon fats by forming them into an emulsion, so that they are readily absorbed. This has been found to take place in artificial experiments by submitting fat substances to the juice at a temperature of 100°.

As would be inferred from the difference of emulsifying power between the saliva and this juice, its organic matter differs from ptyaline. It is estimated that the standard secretion of it is from five to seven ounces per diem. The action of the pancreatic juice appears to be limited to the upper half of the intestine.

2d. The *Enteric* juice is secreted by the organs known as Brunner's glands, the structure of which has a certain analogy to the preceding, and, like it, these doubtless belong to the salivary group. Brunner's glands occur chiefly in the upper part of the small intestine, presenting themselves in the submucous tissue thereof as little bodies, commonly compared by anatomists to hemp-seeds. They consist of lobules with ducts communicating with a common outlet. Their secretion possesses a more energetic power when mixed with bile and pancreatic juice, than the pancreatic juice alone, in producing fatty emulsions.

Fig. 15.

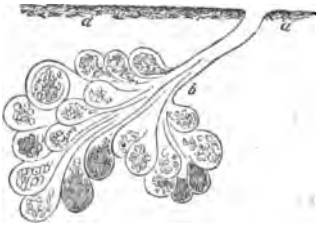


Diagram of Brunner's glands.

In *Fig.* 15, a half diagram of one of these glands, *a a* represents the mucous surface of the intestine, and *b* the lobulated gland, discharging its secretion through a common duct.

3d. The *secretion of the follicles of Lieberkuhn*, which, as shown in *Fig.* 16, are straight, narrow, cæcal depressions of the mucous membrane, found all over the small intestine, and in a general manner analogous to the tubular follicles of the stomach. Their interior is lined with columnar epithelium, and in depth they are equal to the thickness of the mucous membrane, their closed

How much of it is secreted per diem? In what portion of the intestine does it operate? Describe the structure of Brunner's glands, and that of the follicles of Lieberkuhn.

ends being therefore in contact with the submucous tissue, and their mouths opening into the intestine. In a state of health they contain a clear mucus-like secretion. In inflammations of the part they are filled with a more opaque, whitish liquid. From their resemblance to the follicles of the stomach which secrete pepsin, it may be presumed that they possess a somewhat similar function; but in the stomach, the resulting secretion is brought in relation with acids; in the intestine, with alkaline bodies; and hence the physiological action may differ in the two positions, though the structure and primary function may be the same.

Fig. 16.

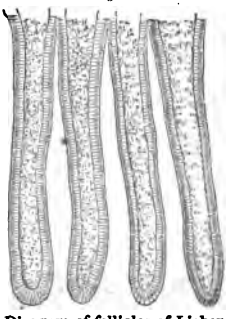


Diagram of follicles of Lieberkuhn.

4th. The *secretion of Peyer's glands.* These may be described as circular spots, of a whitish color, and about the tenth of an inch in diameter, constituting glandular patches full of cell germs, but without any excretory duct opening into the intestine. It is supposed that they discharge their contents by rupturing at a certain stage of their development. The solitary and agminate glands appear to belong to the same physiological group.

The two conditions of the Peyerian glands are shown in *Fig.* 17, the right one being empty, its contents having been discharged, the left one still full. By some it is denied that these bodies are connected with intestinal digestion. The facts that vascular loops pass into their granular contents, and that the lacteals bear a definite relation to them, seem to indicate that they are rather portions of the absorbent mechanism.

Fig. 17.



Peyerian glands.

Describe Peyer's glands. To what system do they probably belong?

5th. The *bile*. Of this it is not now necessary to give a detailed description, since that will occur more appropriately in treating of the functions of the liver. For the present purpose, it is sufficient to state that bile is a greenish-yellow liquid, of bitter taste and alkaline reaction.

It does not appear to exert any agency in effecting the digestion of either nitrogenized or amylaceous bodies. The period of its maximum production, which is 13 or 14 hours after a meal, does not coincide with the period of most energetic digestion.

With these statements of the nature of the various juices passing into the small intestine, we may proceed to investigate the phenomena of the digestion carried on in that tube.

Of respiratory elements, starch is one of the most important, occurring as it does in abundance in vegetable food. It can not be made use of in the system without first being transmuted into dextrine, sugar, and eventually lactic acid, these changes being greatly expedited if it has been previously prepared by boiling in water, or other equivalent operations of cooking. The saliva commences the action, which in man is even prolonged in the stomach, and in the herbivora still more decisively in the paunch, in birds in the crop. On gaining the stomach, the farther transmutation of the starch is arrested by the gastric juice, but after reaching the duodenum it is resumed with greater energy than ever, under the influence of the pancreatic juice. Reaching the ileum, the intestinal juice continues the action, though with less vigor. In this passage to the large intestine, the starch is gradually assuming the condition of dextrine and sugar, the former substance passing into the latter with such facility that it can only be recognized transiently. Doubtless the sugar thus arising is in great part directly absorbed, though some, before the cæcum is reached, is transmuted into lactic acid, and other portions, after passing through the ileo-cæcal valve, into butyric acid.

What is the bile? Is it concerned in digestion? What is the time of its maximum flow? What change must starch undergo before absorption? What juices accomplish that change? What becomes of the sugar arising?

From what has been observed respecting starch, it may be inferred how important sugar is, since through the condition of sugar alone is starch available for the uses of the system. It is to be recollected, however, that sugar itself is only an intermediate or transitory stage, a consideration which explains the circumstance that it does not occur even in the portal blood to such an extent as might be expected, nor yet in the chyle. Some have been led to infer from these facts that this substance, like gum, is in reality only very tardily absorbed, an opinion they suppose to be strengthened by the circumstance that glucose or any other kind of sugar, introduced into the jugular vein, runs through the course of the circulation, and is secreted unchanged by the kidneys. But it is to be remembered that portal blood is very different from the proper systemic blood, and that there are many changes, beyond all question, taking place with rapidity in the former, but which do not take place in the latter.

Sugar, whether it has been received as an ingredient of the food, or arisen from the metamorphosis of starch, is, as we have said, only a temporary form, passing quickly onward to the state of lactic acid. To this we must impute the acid reaction observed throughout the length of the small intestine, and which can not be attributed to the gastric juice, a reaction occurring in spite of the alkalinity of the bile and pancreatic secretion. This pushing forward to the state of lactic acid is very generally imputed to the intestinal juice, which greatly re-enforces the power of the saliva and pancreatic fluid.

On examining the process of the production of lactic acid during the souring of milk, we observe that every thing depends on the change occurring in the nitrogenized principle, the casein. This, under the circumstances, takes on an incipient oxidation, and compels the sugar atom so to divide as to give rise to the production of lactic acid. This ceases the moment the casein ceases to change, and recommences the moment the ca-

What fact has led to the supposition that sugar and gum are tardily absorbed? Into what does sugar change? What juice occasions this? Describe the production and properties of lactic acid. What are the circumstances under which lactic acid arises in milk? In that change, what is the influence of the casein?

sein is permitted to reoxidize. The destruction taking place in the casein is propagated to the sugar, the physical peculiarity being that each atom of sugar is merely divided, fissured, or split, and gives rise to the production of two atoms of lactic acid, and no other substance. The whole process is therefore essentially one of subdivision, a conclusion to be carefully borne in mind in applying these experimental principles to the physiological function of digestion. So far as the result is concerned, the two cases are the same.

We can not here fail to remark how the process of comminuting the food is carried forward to such an extent that the absorbent vessels are able to take it up. The action first begins, as has been shown in detail, by cutting and crushing implements, the teeth, and when these have carried the subdivision as far as mechanical means can, it is continued by chemical agents. Upon these principles, the pancreatic juice divides starch into lactic acid in duodenal digestion — a product which, without difficulty, finds its way at once into the system.

Besides starch and sugar, there is another group of bodies belonging to the class of calorifacient food. In the case of carnivorous animals it seems to be exclusively employed. The fats and oils constitute this group.

The action of the pancreatic and enteric juices upon these bodies is to bring them into the condition of an emulsion, as may be easily proved experimentally. That this occurs in the intestine appears from the fact that if the pancreatic duct be tied, no emulsion forms, and the chyle in the lacteals is limpid instead of being milky. In the rabbit this duct opens much lower in the intestine than the biliary, and it is observed that it is only after the food has passed that point that it becomes emulsioned. The place for pancreatic digestion seems to be very constant in tribes that are far apart in habits of life. Thus, in fishes, the pancreas consists of a coronet of cæcal tubes, surrounding the pyloric extremity of the intestine, each opening into that organ by a separate mouth.

What is the true nature of the change of sugar into lactic acid? What is the general nature of digestive operations? What is the calorifacient food employed by carnivorous animals? What action do the pancreatic and enteric juices exert on fats?

The fats reach the duodenum without undergoing any change. There, under the influence of the pancreatic juice, they become subdivided into extremely minute portions, which, absorbed by the lacteals, give to the chyle its characteristic aspect. Beyond this condition of subdivision no other change is thus far impressed, the fat of the lacteals being absolutely the same as that of the chyme. To the introduction of fat into the lacteals, the presence of bile seems to be necessary, or, if not absolutely necessary, absorption is greatly facilitated by it.

Directing our attention now more particularly to the phenomena displayed by a changing nitrogenized principle, the following illustrations will serve to show that there is nothing mysterious in its operation. Out of many cases that might be selected, those now to be offered are more particularly interesting, since they refer to substances extensively used in the diet of man.

First, of wine. A grape, if perfectly sound, will keep for a considerable length of time without undergoing any change; but if a puncture be made in it to give the air access, it rapidly deteriorates. The precise change taking place is perhaps better understood by observations on the expressed juice of this fruit. If grapes be pressed beneath the surface of quicksilver, and the juice be collected in an inverted jar, without ever coming in contact with the atmospheric air, it may be kept for a long time without any apparent change; but if a small quantity of air, or only a single bubble of oxygen is permitted to enter the jar, and the temperature is that of a summer's day, a commotion or fermentation at once ensues, carbonic acid escapes, alcohol arises in the liquid, and the sugar which was in the grape-juice disappears. But the quantity of sugar thus capable of being destroyed is limited, and a point is eventually reached at which no more sugar can be decomposed, and no more carbonic acid set free.

The juice of the grape contains a nitrogenized princi-

Do the fats undergo any change before reaching the duodenum? Describe what occurs to them there? What condition is necessary for the activity of changing nitrogenized bodies? Illustrate their action from the making of wine. How is it that, in that operation, carbonic acid and water arise?

ple resembling albumen. It is this which is in reality the active body. So long as oxygen is excluded, this nitrogenized substance remains unaltered, but the moment the air finds access a change begins. The sugar present in the juice becomes involved in the movement going on; this is propagated by degrees to all its atoms, dividing each into two well-known and well-marked bodies. The period at which no farther change takes place in portions of sugar which may have been purposely added is when the nitrogenized principle has disappeared.

Carbonic acid and alcohol are the two substances arising in this decomposition. Their mode of origin is obvious when it is understood that one atom of sugar can be so divided as to yield four of carbonic acid and two of alcohol.

Second, of bread. If, in the preceding case, a transmuting nitrogenized body breaks the sugar atom so that alcohol is one of the products, and upon this principle all wines and intoxicating liquors are made, the instance now presented is of far more interest to the well-being of man. The use of wine undoubtedly adds not only to social enjoyment, but sometimes conduces to health—a benefit, alas! often attended with a thousand ills. Not so with bread, emphatically and truly described as the staff of life.

The making of wine and of leavened bread are two of the oldest chemical processes. Their origin is lost in a remote antiquity, and so universally are their benefits acknowledged that their use is diffused all over the world.

Experience proves that the best bread is made from fine wheaten flour, mixed into a paste with a due proportion of water. A certain quantity of a nitrogenized substance undergoing incipient oxidation, termed yeast, is added, and the whole submitted to a gentle temperature. All flour contains a small quantity of sugar; on this the yeast immediately acts, dividing it, as in the former case, into carbonic acid and alcohol. If enough sugar is not present, more under the circumstances is formed from starch. The acid gas, as it is set free, can

Illustrate it from the making of bread. What is the use of the yeast in that operation?

not extricate itself from the surrounding dough, but expands into a thousand little vesicles or bubbles, which give that peculiar porosity for which this kind of bread is so highly prized. At this period, before baking, the other substance arising from the destruction of the sugar—the alcohol—is contained in the dough, and is expelled therefrom along with the excess of water by the high temperature of the oven, which also, by increasing the expansion of the included gas, adds to the porosity of the bread.

On some occasions, instead of using yeast, a piece of leaven, that is, dough in a state of incipient putrefaction, is employed. The mode of action is, however, the same. The use of this material well illustrates the progressive nature of these changes, and how the action gradually passes from point to point of the entire mass. "A little leaven leaveneth the whole lump."

In the cases here presented the action is one of subdivision. A complex atom has its constitution broken up, and is separated into distinct parts. When such a change is once commenced in a mass, there is a liability for the whole to become involved, just as, when we ignite one point in a pile of combustibles, the fire spreads throughout; or as, when on one part of a piece of fresh meat a small portion in a putrescent state is laid, the corruption, with measured rapidity, proceeds from part to part, until the whole is decayed. One after another, the particles submit in succession.

Over all these subdividing actions heat exerts the most extraordinary influence, so that for a given effect to be produced it is absolutely necessary that a given temperature should be maintained. Thus, if we take the saccharine juice of almost any kind of fruit, and cause it to be acted on by a changing nitrogenized body, it will yield, as just stated, alcohol and carbonic acid so long as the temperature ranges about 75°; but, every thing remaining the same, if the temperature be raised to 100° or 120°, neither alcohol nor carbonic acid is formed, but in their stead other products arise, such as

What becomes of the alcohol of the dough? How is it that leaven acts? What is the chemical nature of these ferment actions? What influence does heat exert over them? Compare the fermentation of fruit juices and milk at different temperatures.

lactic acid, gum, and manna. Though, therefore, decomposition will go on throughout all this range of temperature, the products will vary very much, alcohol being formed at a low, and lactic acid at a high degree.

Again, the decomposition of milk furnishes a very instructive instance. When the temperature ranges from 50° to 75°, the liquid turns sour, owing to the formation of lactic acid; but if the temperature is over 90°, the products are different, for now a true vinous fermentation sets in, alcohol and carbonic acid appearing. It is on this principle that the Tartars make an intoxicating liquid from mare's milk. The fermentation of milk, therefore, yields lactic acid at a low, and alcohol at a high degree.

On comparing these illustrations, the results stand in direct contrast, but both show the great influence a specific degree of heat exercises over such subdivisions; and, as a consequence of this principle, which obtains equally in the physiological case, we recognize the necessity of maintaining the cavity of the stomach and intestine uniformly at a fixed temperature, otherwise there would cease to be any uniformity in the subdivision of the food, occasioned by the digestion there going on. These principles, moreover, lead to the explanation of the action of such stimulating substances as alcoholic liquids, pepper, etc., which at once determine a local elevation of temperature; they also explain the injurious effects ensuing from intemperate draughts of ice-cold water.

A nitrogenized substance, in a state of change, can thus bring about a definite action on fibrin, coagulated albumen, or casein in the stomach, or on starch in the intestine, so long as a temperature of 100° is maintained, but in every known instance this transmuting power is totally destroyed by exposure to a very low or very high degree of heat. Large masses of animal matter—whole carcasses—may be preserved for many centuries unchanged if the temperature is kept down to 32°. A striking example of this occurs in the case of the extinct mastodons occasionally thrown on the shores of the Polar Sea from icebergs, in which they have been en-

Why is it injudicious to use undue quantities of ice water?

tombed for many thousand years, their flesh remaining in a perfectly fresh and undecayed state. And as respects a high temperature, an exposure to 212° totally destroys the power. On this principle, all kinds of meat or vegetable substances may be indefinitely preserved. If such are inclosed in metallic canisters, so as totally to exclude the atmospheric air, and exposed to a bath of boiling water, they may then be carried round the world without undergoing any change.

From a review of all the preceding facts, we may conclude that a nitrogenized substance secreted by the follicles of the stomach, and undergoing incipient oxidation, acidulated with hydrochloric acid obtained by the decomposition of common salt, or with lactic acid produced by a continuation of salivary digestion, has the power of dissolving coagulated albumen, and generally those articles of food belonging to the nitrogenized class; that this goes on in the stomach, it being the function of that organ to effect the digestion of this kind of food, and thereby contribute to the general nutrition of the system. The muscular tissues are supplied from this source, and by the stomach their waste is repaired.

Another and distinct digestion takes place in the intestine, commencing immediately after the food gains the duodenum. It too is brought about by the action of a special liquid, a mixture of the pancreatic and intestinal juices. The chemical reaction of this juice is alkaline; in this respect it is therefore antagonistic to the gastric juice. This quality is due to the soda it contains, a substance derived co-ordinately with hydrochloric acid from the decomposition of common salt. The digestion of starchy and saccharine bodies is thus effected by dividing them so as to produce lactic acid.

This done, common salt is reproduced by the commingling of the gastric, biliary, and pancreatic products together. The salt is carried by the absorbents into the interior of the system, to be again decomposed.

Moreover, the pancreatic and enteric juices reduce the oleaginous and fatty bodies to the condition of an

What is the effect of a high temperature on ferment? Compare together the digestive operation going on in the stomach and that going on in the intestine. How is it that the common salt is used?

emulsion, or, if they be not present in the food, give origin to them.

Of the salt substances usually occurring in the food, most disappear during their passage through the intestine; more particularly is this the case with those of a very soluble kind. Of the sulphates and chlorides of the food, not even a trace may occur in the excrement. If these substances should not be required for the uses of the system, they are promptly removed by the kidneys, and in the same manner are disposed of any abnormal salt substances which may have been purposely administered, as, for instance, iodide of potassium.

The gaseous contents of the intestine originate in part from the air that has been introduced during the mastication of the food, in part from fermentative processes occurring after certain articles have been used which are only imperfectly digested, and in part from the endosmosis of gas from the blood through the walls of the intestinal capillaries. As compared with atmospheric air, though the composition must necessarily be very various, the intestinal gas shows a great excess of carbonic acid and nitrogen, a diminution and sometimes even a total absence of oxygen, the presence of pure hydrogen, and of its carburets and sulphurets. The quantity of this latter gas is less than might be expected, and, as would be anticipated from the circumstances, the accumulation of gas is much more abundant in the large than in the small intestine.

As the digested mass passes onward, driven by the peristaltic motions through the convolutions of the intestine, it becomes of a more solid consistency, the absorbents gradually removing the liquid portions. By the time it has reached the cæcum, the same effect which arose in the stomach from salivary digestion is repeated, for the traces of unabsorbed lactic acid cause nutritive digestion to be again feebly resumed, at all events in herbivorous animals, if not in man, whose cæcum is rudimentary, under the form of the appendix vermiformis. The effete remains are finally voided as fæces. Their

From what have emulsions arisen? What becomes of the salt substances as the food advances in the intestine? What are the chief intestinal gases? How have they originated? What occurs in the cæcum of the herbivora?

average, exclusive of water, is only about 1¼ ounce per day. These excrementitious remains, colored yellow by the coloring material of the bile, are partly derived from the residues of the food which have been unacted upon, and partly from the decay of the system itself. The microscope shows the remains of cell membranes, and the walls of vegetable vascular tissues, starch granules, and chlorophyll, the relics of cartilaginous and fibrous tissues, shreds of muscular fibre, fat-cells. From the digestive tract there have been derived mucus corpuscles, epithelial cells, and the coloring matter of the bile. Perhaps, too, much of the water which gives consistency to the fæces has been derived from the intestinal walls, for in quantity, under certain circumstances, it may exceed the amount that has been used as drink. In fact, nearly one fourth of the whole quantity of water in the body has exuded into the intestine and been reabsorbed.

It is interesting thus to observe how the death of one part of the body ministers to the life of the rest; for the nitrogenized and active principles of the juices secreted for the accomplishment of digestion are in a descending career, and are truly dying matter. The incipient stage of decay through which they are passing reacts on the food, and prepares it to replace those parts of the body which are ceasing from activity, and about to be removed.

What becomes of the coloring material of the bile? Of what do the excrementitious residues consist? Why is it that the intestinal water may increase so much? What advantage is taken of the decay of material in the body?

CHAPTER V.

OF ABSORPTION.

Double Mechanism for Absorption.—The Lacteals and Veins.—Lacteal Absorption.—Description of a Villus.—Introduction of Fat by the Villi.—The Chyle.—Causes of the Flow of Chyle.—Intermediate Changes on its Passage to the Blood.—Action of Peyer's Bodies.—Lymphatic Absorption.—Nature of Lymph.—Structure of the Lymphatic System.—Function of the Lymphatic System.—Production of Fibrin.—Cutaneous Absorption.—Causes of the Flow of Lymph.—Apparent selecting Power of the Absorbents.

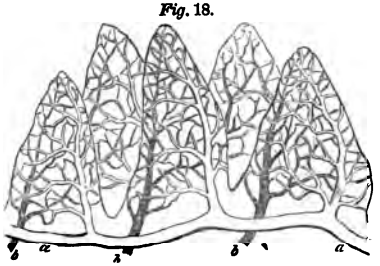
THE food, after digestion, though in the alimentary tract, is exterior to the animal system. Means have therefore to be resorted to for its introduction into the circulation, and its distribution to every part. This is accomplished by a double mechanism, one portion of which is adapted to the digestion occurring in the stomach, the other to that completed in the intestine. The veins profusely spread on the walls of the digestive cavity constitute the former apparatus, the lacteals the latter.

THE LACTEALS AND MESENTERIC GLANDS. ABSORPTION OF FAT.

The lacteals may be described as delicate tubes, conveying materials absorbed from the intestine into the blood. Their mode of origin may be understood by considering them as projecting with a fine but blunt end from the inner coat of the intestine. The projection is covered over with smooth muscle cells and a plexus of blood-vessels, a continuation, as it were, of those of the mucous coat of the intestine itself; they are held together by connective tissue, and over that is cast a covering of cylindric epithelium. This construction constitutes what is called a villus, the shape of which is coni-

What is the object of absorption? Of what use are the veins in absorption? Of what use are the lacteals? Describe a lacteal. What is a villus?

Fig. 18.



Distribution of arteries and veins on villi of monkey.

cal, or perhaps cylindrical. The villus may then be regarded as a process of mucous membrane.

Fig. 18 represents the distribution of blood-vessels to the villi of the intestine of the monkey. The figure was drawn by the camera lucida, *a a* being the arteries, *b b* the veins.

Fig. 19.



Distribution of blood-vessels on the villi of the duodenum.

The form of the villi differs in different regions of the intestine. In the duodenum they are less elevated, laminated, and broader, *Fig.* 19. In the jejunum, more projecting or cylindroid, *Fig.* 20, p. 68. In all cases, however, they are abundantly supplied with blood-vessels. Their epithelial covering of cylindroid cells is shown in the sectional diagram, *Fig.* 21, *a a*, p. 68; at *b b* is the origin of the lacteal arising obscurely.

So amply are the villi supplied with blood-vessels, that if, after injection with coloring material, their cylindric epithelium be removed, they seem to be tinged all over. Each cell of the epithelium appears to be filled with granular matter, and to have a well-marked nucleus. Some anatomists assert that that end of these cells nearest the cavity of the intestine is in reality open, and in

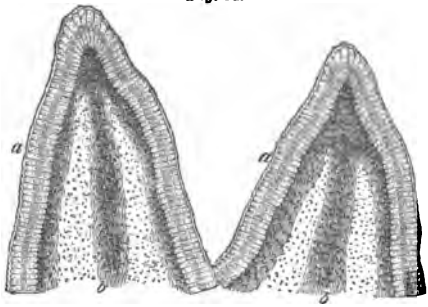
What is the form of the villi in the duodenum? What in the jejunum? What opinion has been entertained respecting their epithelial cells?

Fig. 20.



Distribution of blood-vessels on the villi of the jejunum.

Fig. 21.



Conical villi in section, with cylindroid epithelium.

this manner they account for the ready passage of oil globules into them, and also for the appearance of solid foreign bodies.

Though we have described the lacteal as a vessel projecting into the interior of the intestine, it is by some viewed rather as a mere excavation in the villus. The villi impart to the mucous membrane an aspect sometimes likened to the pile of velvet. On an average, their number upon a square inch is about 10,000. The entire number of these organisms, consequently, must amount to many millions. At one time it was supposed that the lacteals open directly into the intestine—an opinion now universally abandoned. The action of each villus is doubtless more complicated than is generally represented, for the organic fibre cells it contains give to it the power of executing rhythmic motions.

When the operation of the lacteal vessels as absorbents was first detected, it was believed that all nutriment is introduced by their means. But there are many

How many villi are there on a square inch? Do they open directly into the intestine? How is it that they can exert rhythmic motions? What error was formerly entertained respecting them?

animals wholly destitute of this system of tubes, for instance, the invertebrates. Even in many fishes the villi are absent. In such cases absorption must necessarily be conducted by the veins. Moreover, though there are no lacteals on the walls of the stomach, nor, indeed, on that part of the intestinal tube which is higher than the place of introduction of the biliary and pancreatic ducts, there are many substances freely absorbed from the gastric cavity when its pyloric orifice is tied. It has already been mentioned that the stomach absorbs water with remarkable rapidity. The doctrine that the lacteals are the exclusive organs of absorption must, therefore, be abandoned, for it is plain that the venous system participates in the duty.

The function of absorption has therefore to be examined from two points of view. As there are two digestions, one producing a perfect solution, and the other an emulsioned, but not dissolved state of the food, so there are two absorbent systems, the lacteals and the veins. The lacteals introduce such substances as are not absolutely dissolved, the oils and fats. The veins appear to take up those substances only which are completely dissolved in water.

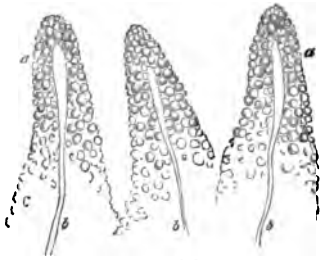
That the lacteals are connected with respiratory digestion seems to be plainly indicated by the circumstances of their occurrence. None of them are found upon the stomach, nor even on that part of the duodenum above the entrance of the hepatic and pancreatic ducts, but below that point they are scattered in profusion all over the small intestine. The digestion of fatty bodies not taking place until the food has gained the duodenum, vessels for the absorption of the emulsions to which that digestion gives rise are not required until after that point is passed. Correctly speaking, however, the lacteals are only lymphatics taking up oil presented to them. In view of the use the oils subserve in the animal economy, the lacteals are in reality an appendix to the respiratory system. There can be no doubt that through their channel oils and fats, under

How many forms of absorption are there? What do the lacteals and the veins respectively absorb? How may it be shown that the lacteals are connected with respiratory digestion? Under what form do they transmit fat to the blood?

the form of emulsions, are transmitted to the blood. The analysis of the chyle shows that it is always rich in fat; and, indeed, it is supposed by some physiologists that the objects just described as cells, surrounding the origin of the lacteals, are nothing more than oil or fat globules accumulated there and waiting to be taken up, or that the disappearance and exuviation of the so-called cells is an optical deception, due to their walls becoming permeated with oil.

The manner in which oil globules collect round the villus I have remarked as being very strikingly displayed in the case of the gray squirrel after feeding on fatty nuts. As shown in *Fig.* 22, the whole structure looks as if it were distended with oil globules, *a a*, in the midst of which the origin of the lacteal, *b b b*, may be discerned.

Fig. 22.



Half-diagram of villi of the gray squirrel after feeding on nuts.

Although it can not be admitted that the production and deliquescence of the cells of villi is a demonstrated fact, and that on this the action of the lacteals as absorbent vessels for the most part depends, the rapid evolution and disappearance of these cells is by no means a physiological impossibility. Botanists assert that, in a single night, the Bovista giganteum, a puff-ball, can develop from a mere point to such a size that it must contain fifty thousand millions of cells—a number that seems almost incredible. The development of cells in the villi of the intestinal tube, in countless crowds, may therefore be within the bounds of possibility.

If this be the case, the cells thus coming rapidly into existence in the villi appropriate those articles of respiratory food of imperfect solubility in water. To this class the oils belong. Each cell then, as it dies, yields up its contents to the lacteal tube. In the white fluid, the chyle, flowing along those tubes, are many pale or colorless corpuscles continually coming into existence. These seem to impress a change upon the chyle, and, to

What may those objects round the lacteals be that look like cells?

give a full opportunity for such action, that fluid is compelled to flow gradually through long and sinuous channels, for the glands in the mesentery may be regarded as convoluted windings, or rather plexuses of tubes, having that particular form for the sake of closeness of package. From the enveloping capsule of fibrous tissue of the glands thin sheets are projected, and so internetted as to divide the whole gland into many alveoli. These are filled with a pulpy material supplied with delicate blood-vessels. The chyle either oozing through this material eventually escapes from the gland by the efferent vessels, or makes the passage in its own thin tube. In reptiles, in which there are no such glands, the lacteals are extended to a very great length.

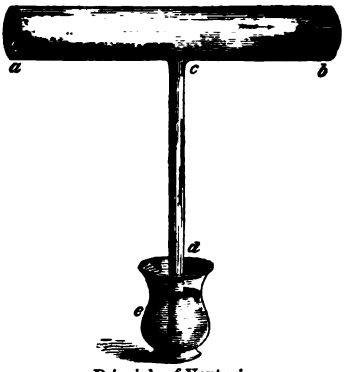
The manner in which the chyle passes through the mesenteric glands is therefore explained differently, according to the view taken of the structure of those organs. If they are considered as mere dilatations of the lacteal vessels, from the sides of which partition processes are sent off, the interspaces being filled with granular material, through which delicate blood-vessels pass, the chyle is to be considered as oozing through this granular structure, and crossing directly in contact with it. But if we accept the doctrine that the chyle is conducted through the gland in a plexus arising from the incoming lacteal, the granular material being outside, then the influence of that material, in whatever it may consist, takes effect through the delicate walls of the plexus. The like remarks apply to the lymphatic glands. Physically, however, the condition in both cases is the same; the incoming liquid is simultaneously exposed in the gland to the influence of the granular pulp and to arterial blood.

Chyle, delivered into the lacteal tube, is propelled by the conjoint action of several different forces. The constant accumulation of liquid at the origin of the vessel produces a pressure only relieved by motion through the tube, and at the mouth, where the lacteal empties into a vein, as sooner or later all do, either directly or through the intervention of the thoracic duct, a suction force is

What is the structure of the mesenteric glands? What influence do they exert on the chyle? Describe the different forces that drive the chyle through the lacteals.

exerted on the contents of the lacteal by the passing current of the venous blood, upon the well-known hydraulic principle of Venturi, that if into a tube, *a b*, *Fig.* 23, through which a current of water is steadily flowing, another tube, *c d*, opens, its more distant end being in communication with a reservoir of water, *e*, through this tube a current will likewise be established, and the reservoir be emptied of its contents. The effect is still greater when the main current is flowing toward the wide end of a conical pipe. Moreover, the lacteal tubes are elastic, and furnished with valves, opening to let the fluid pass toward the veins, but closing in the opposite way. This valvular mechanism renders available any pressure arising either from the contractility of the vessels themselves, or from those various muscular movements, respiratory or voluntary, which affect the abdominal walls. The manner of introduction of the great lacteal trunk —the thoracic duct—at the angle of junction of the left subclavian and jugular veins, is also very felicitous, for the suction force of those large vessels is there conjoined, and the effect is at a maximum. The control of the blood motion on the chyle motion is obvious from this, that as soon as the circulation stops the chyle stops, and this not so much from the engorgement of the venous trunks, rendering it difficult for the chyle to make its way into them, as from the cessation of that tractile force, which solicits the chyle to move into the blood.

Fig. 23.

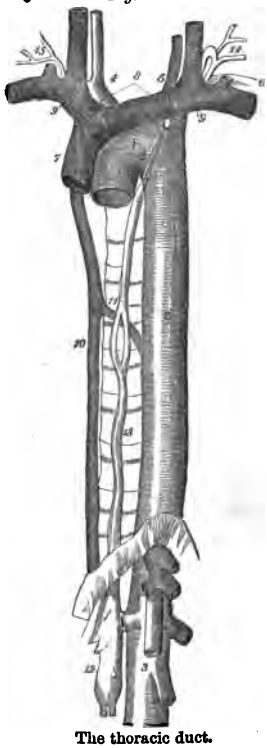


Principle of Venturi.

Fig. 24 represents the position and course of the thoracic duct, and its manner of introduction of the chyle into the blood circulation.

What is meant by the principle of Venturi? How does it come into play on this occasion? What is the thoracic duct?

Fig. 24.



The thoracic duct.

1, Arch of aorta; 2, thoracic aorta; 3, abdominal aorta; 4, arteria innominata, dividing into right carotid and right subclavian arteries; 5, left carotid; 6, left subclavian; 7, superior cava, formed by the junction of, 8, the two venæ innominatæ, and these by the junction, 9, of the internal jugular and subclavian on each side; 10, the greater vena azygos; 11, the termination of the lesser in the greater vena azygos; 12, receptaculum chyli, several lymphatic trunks opening into it; 13, the thoracic duct, dividing opposite the middle of the dorsal vertebræ into two branches, which soon reunite; the course of the duct behind the arch of the aorta and left subclavian artery is shown by a dotted line; 14, the duct, making its turn at the root of the neck, and receiving several lymphatic trunks previously to terminating in the posterior aspect of the junction of the internal jugular and subclavian vein; 15, the termination of the trunk of the ductus lymphaticus dexter.

As to the manner in which digested fat finds its way into the lacteals, it seems to be as follows: In the interior of the epithelial cells oil-drops are detected, while on the outer part the surface presents a pearly aspect, from other portions of oil waiting to enter. By degrees, all the cells upon the exterior of the villus exhibit the same appearance, the particles gradually finding their way through the parenchyma of the villus, and so entering the lacteal tube. In passing through interstices

Describe *Fig.* 24. In what manner do the fats find their way into the lacteals?

too minute to be seen even by optical aid, the oil particles may be pressed out into long, thread-like forms, which, as soon as they escape into the free cavity of the lacteal, assume the spheroidal appearance by reason of their own cohesion, just as a blood-cell can pass through a vessel of a diameter far less than its own by lengthening itself out into a linear shape, and reassuming its original figure as soon as it escapes from confinement and pressure. Though, therefore, the lacteals commence upon the intestinal walls as closed tubes, this, in reality, offers no obstacle to their absorbing power when their molecular porosity is considered.

Perhaps this infiltration or intrusion of oily material is, to a considerable extent, aided by the presence of the bile. It is capable of demonstration that oil will rise much higher in a capillary glass tube, the inside of which has been coated over with bile, than in one which has not been so prepared.

The liquid gathered into the lacteals from the intestine pursues its course to the veins, and ultimately enters them. The special changes impressed on it during this passage will now be explained.

The constitution of the chyle varies with the physiological conditions of the system. After a period of fasting it is colorless, and presents the general appearance of lymph, hereafter to be described, but during digestion it is a whitish milky fluid, whence its name. This milkiness depends on the suspension of minute fat or oil globules in it. Their diameter is commonly stated at the $\frac{1}{3000}$ of an inch. Of course, the composition of the chyle varies in different animals, and even in the same animal under different diets.

How is it that the fat globules can pass through pores of less size than themselves? What effect does the bile exercise? Into what vessels does the chyle ultimately pass? What variations in composition does the chyle exhibit?

Composition of Chyle.

	Horse.	Man.
Water	935.00	904.80
Fat	15.00	9.20
Fibrin	.75	70.80
Albumen	35.00	
Extractive	6.25	10.80
Salts	8.00	4.40
	1000.00	1000.00

With so many causes of variation, such a table as the preceding is only valuable as giving a general idea of the nature of the chyle. We learn from it that the predominating solid constituents are fat and albumen. The percentage amount of the first of these in the sample of human chyle is very low, a fact due to the circumstance that the subject from which it was obtained—an executed criminal—had eaten but little for some time before his death. In like manner, the chyle of horses kept without food has been observed to exhibit a diminution of its fat to such an extent as to be less than one tenth of the normal amount. It is to be remarked that the saline ingredients of the chyle closely represent those of the blood, both in constitution and amount.

The composition of the chyle varies at different points on its passage to the veins, there being a gradual diminution of the albumen and an increase of the fibrin. After the passage through the mesenteric glands it becomes capable of coagulation, and will separate into a serum and a clot. Examined near the villi, it may be regarded as an albuminous liquid, containing suspended globules of fat of various sizes, down to the degree of minuteness just specified. The nature of these globules is determined by the action of sulphuric ether, which readily dissolves them. After passing through the mesenteric glands, the percentage amount of albumen declines, and the fat globules diminish in number. Simultaneously the special cells, chyle corpuscles, make their appearance, and the liquid is now capable of coagulating, owing to the production of fibrin. These characters become more strikingly developed as the chyle advances

What are its characteristic ingredients? What change does it exhibit after passing the mesenteric glands?

in the thoracic duct. The chyle corpuscles are eventually developed into red blood-cells.

It should be borne in mind, in all discussions respecting the composition of chyle in different parts of its course, that it must receive transuded matters from the blood, and that this must more particularly occur on its passage through the mesenteric glands. Owing to this, it is quite probable that, even though there should be an actual consumption of albumen in accomplishing the metamorphoses taking place, the apparent percentage amount of that ingredient may increase by transudation from the blood. It appears to me quite probable that the albuminous material in the lacteal, at its very origin in the villus, has been derived to quite as great an extent by transudation from the plexus of blood-vessels as by absorption from the digested food.

Whatever may be the special manner by which the fats pass from the intestine into the lacteals, they have scarcely gained those vessels before they undergo a change. The quantity of free fat diminishes, and that of saponified fat increases; this is probably accomplished by soda obtained from the blood.

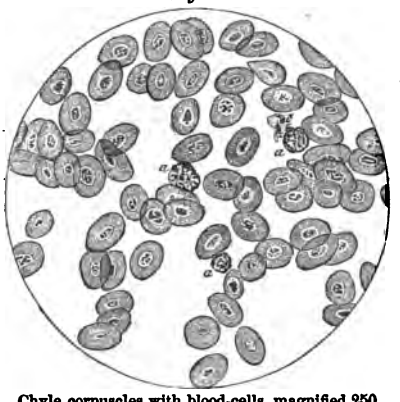
As to the fibrin, it can scarcely be supposed that the imperfectly coagulable variety the chyle contains should have been derived by transudation through the vessels of the strongly contractile kind contained in the blood; and, in view of all the circumstances of the case, it would appear that the explanation we shall offer of its direct origination from the chyle albumen by oxidation is correct.

The chyle corpuscles are readily distinguished from the blood-cells, not only by their white appearance, but also by their form. They are spheroidal, and either homogeneous or granular. Those of the frog are seen in *Fig.* 25, at *a a*, sparsely scattered among the elliptical blood-cells. The photograph from which the engraving is taken exhibits nearly the average proportion of these bodies in that animal.

In embryonic life, the first appearance of chyle cor-

What do the chyle corpuscles eventually become? How do matters transuding from the blood affect the chyle? What change occurs to the fats in the lacteals? Compare the chyle corpuscles and blood-cells.

Fig. 25.



Chyle corpuscles with blood-cells, magnified 250 diameters.

puscles commonly coincides with a change in the arrangement of the respiratory mechanism, as the closing of the branchial fissures, indicating a connection between their production and the activity of interstitial oxidation.

The bodies known as Peyer's glands are to be regarded as belonging to the absorbent rather than the digestive apparatus. In structure they are analogous to the lymphatic glands, consisting of a capsule containing granular material, in which loops of capillary blood-vessels are laid. From these proceed many lacteal vessels, as may be very plainly observed during digestion. Their functions would therefore seem to be the submitting of the chyle to the simultaneous influence of the blood brought by the arterial capillaries, and the pulpy material or granular plasma they contain. They are, in reality, intestinal mesenteric glands.

THE LYMPHATICS AND THEIR GLANDS.

It is not possible clearly to understand the functions of the lacteals without a description of the structure and functions of the lymphatics, for these vessels conspire in their action.

Anatomical, chemical, and physiological considerations lead us to conclude that the formation of the LYMPHATIC SYSTEM is closely allied to that of the LACTEAL. The two classes of vessels make their appearance together in fishes; the lymphatics originate in a network of delicate tubes, but are disseminated through all the soft tissues

When do the chyle corpuscles first appear? What is the structure and probable use of Peyer's bodies? How are the lymphatic and lacteal systems allied?

except the nervous, and are found especially in the skin. The fine initial tubes gradually coalesce, producing those that are of a larger diameter, and these pass through glands, which might indeed be regarded as mere plexuses, and eventually empty into the veins.

A few minutes after it has been drawn, the lymph coagulates into a colorless clot, and then exhibits contraction. Compared with blood in like circumstances, the clot of lymph is small in relation to the serous portion. In other respects there is a general resemblance between lymph and blood free from its red cells, the fibrin and the albumen being apparently the same in the two cases. The saline constituents are not only the same, but bear the same ratio to one another in the two fluids. Their absolute percentage amount differs, because the lymph contains a larger proportion of water than the blood.

Lymph arising, as we shall find, by transudation from the capillaries, must obviously vary in different parts, those parts taking from the blood the materials they require for their nutrition, and yielding to it the products that have arisen during their waste. Whatever in this manner changes the composition of the blood, must also occasion a change in the transuded liquid. Not only must the material thus oozing from the capillaries vary in different regions, because of variations in the mechanical constitution of those vessels, but it must also change even in the same locality, through temporary accidents, such as changes in the velocity with which the blood is flowing. An attempt has been made to show that the transudation will be richest in albumen as the blood current in the capillaries is slower.

When the contents of the lymphatic vessels are submitted to analysis, and compared with the chyle, a striking difference is apparent. The chyle contains, as has been already stated, large but variable proportions of fat or oil in an extremely subdivided state, from which the lymph is free. The leading solid constituent of the lymph is albumen, and this indicates the use of the system.

Describe the properties of lymph. What is the relation of its saline ingredients to those of the blood? What is the origin of lymph?

Composition of Lymph.

	Horse.	Man.
Water	950.00	961.00
Fat	.09	
Fibrin	39.11	2.50
Albumen		27.50
Extractive	4.88	6.90
Salts	5.92	2.10
	1000.00	1000.00

The constitution of chyle after a period of fasting is the same as that of the lymph. The presence of chyle in the lacteals is therefore not a constant but a periodical phenomenon. The analogy of composition between lymph and chyle shows clearly that the albumen of the latter is rather derived from the blood capillaries than from the digested food.

There can be no doubt that the office of the lymphatics is to collect the albuminous matters which have every where transuded from the blood-vessels, or been set free by changes going on in the soft parts. Such matters, though they may be regarded as being in one sense dead, are yet as applicable for the farther support of the mechanism as are the albuminoid bodies introduced as food, and said to be taken up by the lacteals. Lymph is really nothing but a diluted serum. A mechanism is therefore resorted to to turn this collected albumen into fibrin, and thus arises a lymphatic gland—a contrivance tending greatly to compactness. This structure is the counterpart of the mesenteric or lacteal gland. It may be described as originating from the coalescence of two or three lymph vessels, which, casting off their external coat as they enter the gland, anastomose with one another in various ways, so as to form plexuses and convolutions. The capsule of the gland, strengthened by the coat it has received from the entering vessels, sends forth partition-like processes, dipping down into the grayish pulpy material that fills the interstices. On their emergence from the gland the vessels recover from it their external coat, and, during their passage through

What is its composition? What is the relation between fasting chyle and lymph? How is it that the presence of chyle in the lacteals is periodic? What is the office of the lymphatic system? Describe the structure of the lymphatic glands.

it in their naked state, blood-vessels are distributed upon them. The object of the arrangement seems to be to submit the liquid contained in the lymph vessel to the action of the pulpy material of the gland and arterial blood under the most favorable circumstances, the thinness of the wall and the convolved plexus being well adapted to that end.

The absorbent vessels, whether lacteals or lymphatics, have therefore a common duty of changing albuminose or albumen into fibrin, and thereby of compensating for the constant waste of that substance going on in the wear and tear of the muscular system. We can not estimate the hourly consumption at less than 62 grains. Such a waste must demand an equivalent compensation, if the animal mechanism is to be kept up unimpaired, and every care is therefore taken to omit no means of husbanding the necessary materials. The action of the lymphatics illustrates this principle significantly. Passing through all the soft solids where exudation of albumen from the blood-vessels can take place, they collect the materials that would otherwise go to waste, and add thereto many of the products arising from the disintegration and decay of the soft parts themselves. Receiving all these, they transmit them through their windings in the glands, and thus submit them to the action of the innumerable cells there coming into existence. As in the egg of a bird, the albumen slowly disappears, and muscular tissues of the young chicken arise, so here the serous portion disappears, and fibrin comes in its stead, and this is hurried forward to the torrent of the circulation, and thrown into the blood-vessels, to be by them distributed to all parts of the mechanism, wherever the muscular tissues are in want of repair.

But, besides this function of the elaboration of fibrin, there can be no question that the lymphatics have other incidental uses. Many facts are known, proving that those of the skin exert a powerful agency in absorbing liquid material. Thus a person who has abstained from water will, after he has immersed his body in a bath, not

From what do the absorbent vessels produce fibrin? How much is its hourly waste? What analogy does the egg of a bird present to these results? How is it known that substances may be absorbed by the lymphatics of the skin?

only find his weight increased, but the sensation of thirst abated. Instances of the kind are on record where sailors, in open boats without fresh water, have assuaged the torments of thirst by immersing their bodies in the sea. Nay, it is even asserted that in certain conditions water may thus be obtained from the atmospheric air, and in all such cases every thing points out that the lymphatic vessels are the avenues through which the liquid is introduced.

In what manner does the lymph move? In reptiles are found what are termed lymphatic hearts; these are merely dilated portions of a tube exhibiting pulsation. In the frog, two pairs may be discovered, one behind the hip-joint, and situated so superficially that the motions can be plainly seen; the other is at the anterior part of the chest. The pulsating movements of these organs, of course, impel the liquid acted on in the direction determined by the valves with which the vessels are so profusely supplied—that is, to the general circulation, and the lymph finally enters the blood-vessels.

But in the higher tribes these organs of impulsion are absent, and the circulation through the vessels is determined by the agencies mentioned in the case of the lacteals. 1st. By the constant accumulation of liquid at the origin of the tube; 2d. By every muscular movement, either voluntary or involuntary, producing a compression of the tube, the valves all opening one way, and therefore causing the included liquid to pass in one direction only; 3d. By the exhaustive action at the mouth of the lymphatic, arising from the passage of the blood. It ought, perhaps, to be prominently pointed out, as belonging to the second of these causes, that the pulsation of the arterial trunks adjacent to any lymphatic brings the power of the heart itself into operation in an indirect way.

Though the absorbents receive many different bodies and transmit them to the veins, the action does not take place in an indiscriminate manner. Certain substances, such as the fats and albumen, find a ready entrance, but admission to others is wholly denied. Thus it has long

Describe the causes which give rise to motion in the lymph. What are lymphatic hearts? What effect do the arterial trunks exert? What is meant by the selecting power of the absorbents?

been known that if coloring matter be introduced into the intestine, it by no means follows that the chyle will be tinged. If an animal be compelled to take litmus water, the chyle will still be found colorless or white. On such facts was founded the old doctrine that these organs possess a low species of intelligence, distinguishing among different substances, permitting some to enter them, and refusing a passage to others. Many years ago I showed that these fanciful cases are capable of a simple physical explanation. Thus I found that if blue litmus water were tied up in a bladder or a piece of peritoneum, and sunk in a vessel of alcohol, though the water would rapidly infiltrate into the alcohol, the coloring matter would be stopped just as it is in the intestine. But, in reality, there is no need of such experiments to satisfy us of the fictitious nature of this selecting power. If we fill a lamp half full of oil and half of water, and immerse in it a wick long enough to dip into both, if the wick be previously soaked in oil, it will withdraw from the lamp oil alone, and continue to do so until the lamp ceases to burn; but if it be first soaked in water, it will wholly refuse to take the oil, and remove the water alone, until all has escaped by evaporation. But did ever any one impute to the wick of a lamp a power of intellectuality, no matter how obscure, or suppose that there is any thing mysterious in such a selecting operation? A perpetual reference of the most common facts to mysterious agencies has been the great barrier to the advance of medical science. This system was introduced by the alchemists and quacks of the Middle Ages, and even now it will take many books and many years before physiology can be rescued from such visionary theories.

How may the selecting power of the absorbents be illustrated?

CHAPTER VI.

ABSORPTION BY THE BLOOD-VESSELS.

Proof of Absorption by the Blood Capillaries.—Occurs as a Physical Necessity.—Nature of Capillary Attraction.—Its Phenomena in the Rise and Depression of Liquids.—Conditions for producing a Flow in a Capillary Tube.—Passage of Liquids through minute Pores.—Endosmosis and Exosmosis.—They depend on Capillary Attraction.—Force against which these Movements may take place.—Illustrations of selecting Power.

THAT the blood-vessels of the stomach and intestinal tube participate in the function of absorption is demonstrated by many different facts. Medicaments placed in the stomach after its pyloric orifice has been tied will produce their specific effect almost as rapidly as under natural circumstances; and, since there are no proper lacteals upon that organ, and its lymphatics seem to be inadequate, the absorption of these agents can have taken place through the blood-vessels only.

This conclusion is substantiated by an examination of the blood of the gastric and mesenteric veins. It varies with the stage of digestion and the nature of the food. At first there is a general lowering of the percentage amount of the solid ingredients, this being evidently the result of the absorption of water. At a more advanced period, the relative proportion of albumen, or rather of albuminose, rises, and along with it the extractive, gelatine, and sugar increase. As with the chyle in the lacteals, so with the blood in the mesenteric veins, coagulation takes place imperfectly, or not at all. The mesenteric blood of a fasting animal does not differ from the ordinary venous blood.

How may it be proved that the blood-vessels of the stomach absorb? What changes take place in the blood of the gastric and mesenteric veins during digestion?

The position of the blood-vessels, both on the mucous surface of the stomach, and particularly on the villi of the intestine, is favorable to the discharge of this function. The term venous absorption, employed to express it, is perhaps somewhat incorrect, since there is no reason that a venous capillary should have any advantage over an arterial one in this respect.

In fact, if there were not these physiological considerations, we should have to admit absorption by the blood-vessels as a matter of physical necessity; for, under the circumstances of their situation, they must take up soluble matters presented to them. Through the pores of their delicate structure substances in the liquid state will pass to mingle with the blood.

Though we have treated of respiratory or lacteal absorption as specifically distinct from absorption by the blood-vessels, the circumstances here alluded to evidently point out that the resulting action of the villi of the intestines is of a mixed kind; for, though the epithelial cells and the commencing pouch of the lacteal may exert a definite influence, the network of bood-vessels which lies immediately beneath the epithelium must be engaged in precisely the same manner as the network of blood-vessels between the gastric follicles. The permeation of the walls of these tubes by substances in a state of solution is dependent, as we are now to see, upon a purely physical principle, just as applicable in the one case as it is in the other.

In absorption, as in respiration, hereafter to be described, there is a physical principle in operation necessary to be understood. I shall proceed to explain it on this occasion as far as is needful for the present purpose, and complete the description in the chapter on the function of respiration. The peculiar views here set forth, so far as they differ from those ordinarily expressed, I believe to be warranted by my own experiments elsewhere published.

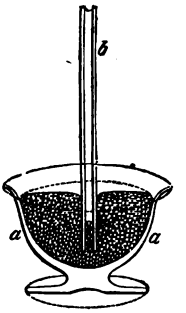
The absorbent action of the blood-vessels depends on the force known among physical writers as CAPILLARY ATTRACTION. Its nature may be illustrated as follows:

Why is the term venous absorption incorrect? Why is venous absorption a physical necessity? What is the reason that the action of the villi is of a mixed kind?

If a piece of glass be laid on the surface of quicksilver, it is so powerfully attracted thereto as to require the exertion of considerable force to lift it off. Natural philosophers generally regard this as a force sui generis, and speak of it under the title of capillary attraction. I believe it is nothing but an ordinary electrical phenomenon, since, if the glass be examined, it will be found to be in a positively electrified state, and the quicksilver negative, and under the general law of electricity, known as that of Dufay, attraction must be the result.

If the glass be laid upon the surface of water, there is an attraction as before. On lifting it, however, there is no electrical manifestation. The reason of this is plain. On examining this glass, it will be found that no true separation of it from the water has taken place. A film of water is still attached to it, or, in other words, it is *wetted*.

Fig. 26.



Depression of a non-wetting liquid.

If a slender glass tube, *b*, *Fig.* 26, be dipped into a liquid, *a a*, which can not wet it, as, for example, quicksilver, the liquid is depressed as at *c*, and does not rise to its proper hydrostatic level, or, perhaps, altogether refuses to enter the tube.

Fig. 27.



Elevation of a wetting liquid.

If a slender glass tube, *b*, *Fig.* 27, be dipped into a liquid, *a a*, which can wet it, as, for example, water, the liquid at once rises in the tube, as at *c*, to a height greater in proportion as the diameter of the tube is less. This phenomenon has given the designation *capillary attraction*, because it is best seen in tubes as fine as a hair (capillus).

Now if there be a tube of such a diameter that it can thus lift water ten inches, and it be broken off so as to

Define capillary attraction. Why is it to be regarded as an electrical phenomenon? Explain the circumstances under which liquids rise or are depressed in a capillary tube.

be only six inches long, we might inquire whether the water would overflow from its top, or simply remain suspended.

Mathematical considerations as well as direct experiments prove that, in such a case, there would be no overflow. A capillary tube under these circumstances simply lifts the water, but can not produce a continuous current.

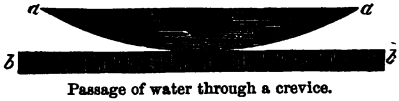
But if a removal of the water at the top of the tube take place in any manner, as, for instance, by evaporation, or by being dissolved away, then a continuous current is produced. This fact explains the phenomena of endosmosis, presently to be described.

As illustrative of the production of a continuous flow, we may cite the case of a spirit-lamp, the wick of which may be regarded as a bundle of capillary tubes. If the cover of the lamp be taken off, all the spirit will pass up the wick and escape by evaporation; or, in an oil-lamp, the wick of which becomes readily saturated with the liquid, but never exhibits any overflow; on the lamp being kindled, the oil is burned off, and a current is at once established.

I have shown that water will pass through a crevice, the width of which is less than one half of the millionth of an inch. Pores or crevices of such a dimension are invisible even with a microscope.

The proof of this is very readily obtained experimentally. If we take a convex lens, *a*, *a*, of long radius, and place it upon a glass plane, *b b*, there will be seen at the point of contact, *c*, on looking down upon the arrangement, a black spot surrounded by a series of variously colored concentric circles, the appearance being well known among optical writers under the name of Newton's colored rings. At the point of apparent con-

Fig. 28.



Passage of water through a crevice.

Can capillary tubes produce a continuous flow of liquid? What is the effect of its removal from the top of the tube? Under what circumstances does a continuous flow in a spirit-lamp or oil-lamp take place? Through how small a crevice will water pass? Explain the fact illustrated by *Fig.* 28.

tact, *c*, the lens and the plane are, as Newton has shown, a distance apart of about the one half of the millionth of an inch, and from this central point, proceeding outwardly, the distance between the glasses, of course, increases. If any where at the outer portion a drop of water be introduced, it extends itself instantly across all the colored rings, reaching even across the central black spot.

The phenomena of endosmosis may be explained as follows: If some alcohol be placed in a bladder, the neck of which is tightly tied, and the bladder be sunk in a vessel of water, a percolation ensues, so that the bladder distends to its utmost capacity, and might even be burst. Or, which is a better method of showing the result, if, instead of tying the mouth of the bladder, a glass tube, open at both ends, and a foot or two long, be fastened into it without leakage, as the water introduces itself through the pores of the bladder to mingle with the alcohol, the liquid rises in the glass tube, supposed to be left in a vertical position, and, when it has reached the top of it, overflows. To express this inward passage of the water the term endosmosis was introduced, and since a little of the alcohol simultaneously passes outward to mix with the water, it is said to exhibit exosmosis.

Fig. 29.



Endosmosis.

In *Fig.* 29 is represented the endosmometer of Dutrochet. It consists of a small bladder, *a*, tightly tied to a tube, *d*, which is open at both ends, and bent, as seen in the figure at *c*; the bladder being completely filled with alcohol, and the tube to some such point as *d*, the arrangement is to be placed in a vessel of water, *e e*; almost immediately the level of the liquid will be seen to be ris-

What is meant by endosmosis? What by exosmosis? Describe the endosmometer.

ing, the bend of the tube is reached, and one drop after another falls from the open end into the glass, *b*. And this continues until the liquids inside and outside of the bladder are uniformly commingled.

It is to be regretted that the terms endosmosis and exosmosis have been accepted by physiological writers, for in these results there is nothing more than what we should expect from the known principles of capillary attraction. The pores of a bladder, or of any other such organic texture, are nothing but short capillary tubes into which water readily finds its way, because it can *wet* the substance surrounding the pore. If the bladder be distended with air, and sunk under water, although the water will fill the pores, it will not exude from them, and accumulate in the interior of the viscus, for, as we have seen, a capillary tube can not establish a continued current or flow. But the case becomes totally different when the bladder is filled with alcohol; for then, as fast as the water presents itself on the inner end of the pores, it is dissolved away by the alcohol, and the necessary condition for a continuous flow is complied with. Meantime, through the pores themselves a little alcohol passes in the opposite way by infiltrating through the incoming water, provided that the current be not too strong, and so endosmosis of the water and exosmosis of the alcohol take place, the current of the former greatly preponderating over that of the latter, and an accumulation of liquid in the interior of the bladder ensues.

That in all this there is nothing specially dependent on the organic texture employed is obvious from the fact that the same results arise when any inorganic porous body is used. Vessels of unglazed earthenware, pieces of baked slate or stucco, answer the purpose very well, as will also a glass vessel with a minute fissure or crack in it.

An incorrect representation of the conditions under which endosmosis takes place is often made. It is said to depend on the relative specific gravity of the liquids. Thus it is stated that the lighter liquid always moves

What connection has endosmosis with capillary attraction? Under what circumstances is there endosmosis into a bladder? How is it known that the organic texture is not necessary in endosmosis? Is the direction of the motion dependent on specific gravity?

toward the denser, more abundantly than the denser to the lighter. The error of this is readily shown by many simple illustrations. Thus water endosmoses equally well to alcohol, which is lighter than it, and to gum water or salt water, which are heavier. The relation of specific gravity has nothing whatever to do with the action.

The force with which a liquid will thus pass through a pore to mingle with another liquid beyond is very great. I have observed these motions occurring against a pressure of many atmospheres. And, indeed, in practice we have no means of measuring its actual intensity; for when a pressure of a certain degree has accumulated, hydraulic leakage takes place backward through the pore, and conceals the true action.

From the preceding statements respecting capillary attraction and endosmosis, we may therefore conclude that, whenever a liquid is in contact with a porous body the substance of which it can wet, it will freely pass into the pores thereof, and, if the necessary conditions for its removal are present, will percolate or transfuse with very great mechanical power; that this will take place through pores that are not only invisible to the eye, but imperceptible by the aid of the microscope; that some liquids pass thus with more readiness, some with less, the result in these respects depending on the electrochemical relations subsisting between them and the solid they are in contact with, and their own force of cohesion; that organic membranes present no peculiarities, their action arising, not because they are organic, but because they are porous; that the so-called selecting power is purely physical, as are the separations and apparent decompositions to which it gives rise. When a drop of colored water is put upon chalk, the water sinks in, but the color is left on the surface. When weak alcohol is tied up in a bladder, the water will escape through the pores, and the spirit become anhydrous at last.

If we take a glass tube, *a a*, *Fig.* 30 (page 90), over the lower end of which a piece of peritoneum, or other delicate membrane, *b b*, is tightly tied, and half fill it

With what force do these motions of liquids take place? How may the selecting power of membranes be illustrated?

Fig. 30.



Selecting power of a membrane.

with litmus water, and then place it in a glass of alcohol, *c c*, the level of the liquids inside and outside being adjusted according to their specific gravity, so that there may be no hydrostatic pressure either one way or the other through the pores of the peritoneum—as soon as the arrangement is completed, if the observer be so placed as to view it by transmitted light, he will see the water descending from the pores of the peritoneum in striæ and streams through the alcohol in a perfectly colorless state. The membrane, therefore, has absorbed and transmitted the water, but has refused to the coloring matter a passage. It is to this particular experiment that allusion was made when speaking of the non-coloration of the chyle after certain coloring material had been mixed with the food. Such illustrations may therefore satisfy us that the selecting power of organic porous textures, like that of inorganic ones, is dependent on simple physical circumstances.

In view of all the preceding facts, I therefore regard absorption by the blood-vessels as taking place of necessity, because of the porous structure of those tubes; for, though the pores may be too small to be discerned even by microscopic aid, they are abundantly large enough to permit such a percolation. Whatever material is existing in the chyme in a state of solution in water and also soluble in the blood, passes through the walls of the blood-vessels, and is moved toward the liver, its percolation being greatly facilitated by the onward motion of the blood, in which liquid it is dissolved as fast as it presents itself. The double condition here specified must be complied with; the material to be introduced must be dissolved in water, and must be soluble in the blood. If the latter condition be wanting, the vessels seem to manifest a selecting power, absorption not taking place,

Describe the experiment of *Fig.* 30. Give a summary of the process of absorption.

as in the case of litmus, presented above as an illustration—a coloring matter which, though soluble in water, is not soluble in alcohol, and so can not, under those circumstances, pass through a piece of bladder.

While thus there is an introduction of digested material from the stomach and intestine into the blood, the physical principles guiding us in our explanation teach us that there must be a percolation of the more watery portions of the blood in the opposite direction—that is, into the digestive cavity. There is every reason to believe that this percolation is to a far greater amount than is generally supposed. Under certain circumstances, it is a matter of ordinary observation that the water discharged from the intestine is more in quantity than that which has been taken as drink.

In the description here offered of the function of absorption, the agency of physical forces alone has been considered, and these I conceive to be abundantly sufficient to enable us to account for all the phenomena.

CHAPTER VII.

OF THE BLOOD.

The Offices and Relation of Blood in the System.—The Plasma and Cells.—General Properties and Composition of the Blood.—Quantity in the Body.—Coagulation.—Blood-cells.—Their successive Forms.—The perfect Cell.—Hæmatin: its Properties.—Plasma: its Composition, and Variations of its Ingredients.—Albumen, Fibrin, Fat, Sugar.—Mineral Ingredients.—Gases of the Blood.—General Functions of the different Ingredients of the Blood.—Introduction of Oxygen by the Cells.—Their transient Duration.

It is necessary for the functional activity of every organized being that there shall circulate through all parts of it a nutritive liquid. In plants it is the sap; in animals, the blood.

Why must there be a percolation of water into the digestive cavities? To what extent may this percolation go? What condition is necessary for the functional activity of plants and animals?

Since the life of plants manifests itself, for the most part, in a purely formative result, and involves little or no destruction of parts, the circulating current is devoted almost entirely to nutrition. But in animals, whose conditions of existence involve extensive and unceasing destruction, the current is burdened with another duty. It is also the means of removal of dying or wasted portions.

In the first chapter it was shown that about a ton and a half of material is required by a man in the course of a year, and that in the same period a like amount is removed from the system. When we reflect that the introduction and removal of this immense mass is accomplished through the agency of the circulating blood, it is obvious that that fluid must be undergoing rapid changes. The elements of decay are strained off or exhaled as quickly as they arise.

Considered in its relation to nutrition, the circulating liquid presents many interesting aspects. Each of the thousand variously-constituted parts of the body is withdrawing the supplies it needs—the muscular, the nervous, the cartilaginous, the bony; and hence there arises a general balance in the system, each part making its demand at a certain rate, and each observing a complementary action to all the rest. Many of those phenomena which, in the infancy of physiology, were regarded as instances of sympathy between different parts, are clearly dependent on these conditions; for the development of one part, by abstracting special material from the circulating liquid, permits the co-ordinate development of another, or perhaps puts a stop to it. The minutest portion of the mechanism is thus indissolubly connected with all the rest through the medium of the blood.

Seen as it circulates in the vessels, the blood consists of a colorless liquid containing corpuscles. In man, some of these corpuscles are white and others red. To the liquid in which they float, the designation of the plasma is given; the colored corpuscles, from their shape, are

What is the difference of function in the two cases? How is it known that the blood changes with great rapidity? In what manner does the circulation establish connections between all parts? Of what two portions is the blood composed? What is the plasma? What are the discs?

called discs or cells. The specific gravity of the blood varies from 1.050 to 1.059, the variation being, to a considerable extent, due to variations in the quantity of the cells. The temperature is about 100° Fahr., the reaction always alkaline; there is also a faint sickly odor, differing in different animals. The cells give to the blood its tint of color, and this, in the systemic arteries, is crimson; in the veins, deep blue. However, the color of arterial blood depends considerably on the condition of respiration. An imperfect introduction of oxygen, as in hot climates, causes the arterial blood to assume a dark color, and the same is observed when chloroform, ether, or diluted irrespirable gases are breathed. The blood of the male sex is heavier than that of the female.

Constitution of the Blood.

Water	784.00
Albumen	70.00
Fibrin	2.20
Discs	131.00
Fats	1.30
Salts	6.03
Extract, urea, biliary matter, etc	5.47
	1000.00

As to the quantity of blood in the circulation, it has been variously estimated. It may perhaps be taken at one eighth of the weight of the body.

A short time after it has been drawn, the blood undergoes coagulation, and is then said to be composed of the serum and the clot. In this state it is sometimes spoken of as dead. The plasma of living blood differs from the serum of dead in containing fibrin.

The coagulation of the blood commences within about ten minutes after it has been drawn, and the clot undergoes a subsequent contraction during one or two days. To understand the physical nature of this singular change, we may conveniently regard the living blood as containing three leading constituents—an albuminous liquid, fibrin dissolved therein, and the cells. The coagulation arises from the tendency of the fibrin particles to agglutinate together. As this takes place, the cells

What are the physical properties and components of the blood? What is meant by the coagulation of the blood? How long does the clot contract? From what does coagulation arise?

are caught in the meshes of the network that arises, and a voluminous red clot is the result. So the serum of dead blood contains no fibrin, and differs from the plasma of living blood in that important particular.

It has been observed that exposure to cold retards coagulation, as does likewise the absence of air, or covering the blood over with a film of oil. The condition of rest promotes it, as also does the presence of rough or angular bodies. Blood will yield up its fibrin readily when stirred with a stick. When, for any reason, the cells sink more rapidly than usual from the surface of the blood, the fibrin of the supernatant portion coagulates alone, giving rise to a stratum free from the red color, and designated the buffy coat, and on the subsequent contraction, since there are no cells to hinder the fibrin, its parts upon this stratum are drawn more closely together, and the clot becomes cupped.

By those who accept figurative expressions as an explanation of physiological facts, the coagulation of the blood is said to be due to its death; some, however, have regarded it as an abortive attempt at organization, and therefore a manifestation of life. Such contradictory explanations lose much of their interest when we examine the facts of the case critically. I believe that nothing more takes place in blood which has been drawn into a cup than would have taken place had it remained in the body. In either case the fibrin would have equally coagulated. The entrapping of the cells is a mere accident. The hourly demand for fibrin amounts to 62 grains; hence the entire mass of the blood would be exhausted of all the fibrin it contains in about four hours, and solidification of fibrin must be taking place at just as rapid a rate in the system as after it has been withdrawn. No clot forms in the blood-vessels, because the fibrin is picked out by the muscular tissues for their nourishment as fast as it is presented, nor would any clot form in a cup if we could by any means remove the fibrin granules as fast as they are solidified.

In entering on a detailed examination of the constitution and functions of the blood, our attention will have to be directed, in the first place, to the cells. It is suf-

What circumstances accelerate or retard coagulation? How does the buffy coat form? What is the explanation of coagulation?

ficient to arrest our thoughts at once when we learn that for every beat of the pulse nearly twenty millions of these organisms die! Physiology has its wonders as well as astronomy.

In the life of man there are three periods distinguished from each other by the nature or structure of the blood-cells. Those of the first period originate simultaneously with, or even previously to, the heart. These are sometimes designated as embryo cells, and in that view bear the same relation to those of the second period as do the lymph corpuscles to those of the third. They are colorless and spherical cells, containing granules of fatty material, and having a central nucleus. These are developed, by a process of internal deliquescence, into cells of the second period, which have acquired a red color, and in oviparous vertebrates an elliptical form, though in man they are circular. They are flat or disc-like in shape, have a diameter of about $\frac{1}{2500}$ of an inch, with a central nucleus of half that size. Sometimes they appear to undergo multiplication by division of the nucleus.

These cells of the second period are replaced by those of the third, the transition being clearly connected with the production of lymph and chyle corpuscles. By the end of the second month of fœtal existence the replacement is complete, and the class of cells or discs that has now arisen is continued during life. The mode of their production is this. The chyle or lymph corpuscle loses its granular aspect, and acquires a pale red color, which gradually deepens; the corpuscle becomes smooth, loses its spherical form, and, condensing, takes on a convex lenticular shape, and eventually a bi-concave. While this change of structure is going on, the specific gravity increases through the condensation, and the development closes by the spherical white granular lymph corpuscle becoming a red, bi-concave, non-nucleated, circular, small, and heavy blood disc.

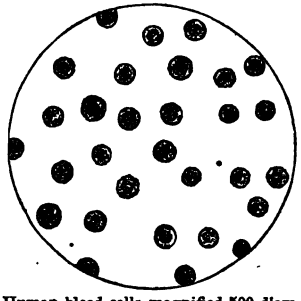
The cell of the first period is therefore spherical, white, and nucleated; that of the second, red, disc-shaped, and nucleated; that of the third, red, disc-shaped, bi-concave, and non-nucleated.

How long do the discs live? How many different kinds of them are there? Under what circumstances does each kind arise?

The primordial cell advances in development to different points in different orders of living beings. The blood of invertebrated animals contains coarse granule cells, which pass forward to the condition of the fine granule cells, and reach the utmost perfection they are there to attain in the colorless nucleated cell of the first period of man. In oviparous vertebrated animals the development is carried a step farther, the red nucleated cell arising, and in them it stops at this, the second period. In mammals the third stage is reached in the red, non-nucleated disc, which is therefore the most perfect form.

This perfect form of blood-cell, as it occurs in man, may be described as presenting a flattened shape; the bright spot, sometimes seen in the centre, arising from a refraction of light due to the form of the disc and not to a nucleus. The sac of each disc is elastic, so that it can be swollen by water until it becomes convex or even globular, or by immersion in thick sirup may be made to shrink, effects arising from the endosmotic infiltration or exudation through its wall. When passing through the fine capillaries in the course of the circulation, the cell, by reason of this elasticity, can make its way through very difficult passages, extending itself into a cylindroid form, but it recovers its original shape as soon as relieved from pressure. The average diameter of the cell is estimated at $\frac{1}{3200}$ of an inch, the extremes being $\frac{1}{2800}$ and $\frac{1}{4000}$. The thickness of the cell is about $\frac{1}{12400}$ of an inch. The cell owes its color to hæmatin, which exists in its interior in a state of solution, and associated with globulin.

Fig. 31.



Human blood-cells magnified 500 diameters.

The facts mentioned in the preceding paragraph are illustrated by the annexed engraved photographs. *Fig.* 31 represents human blood-

Describe the perfect blood disc or cell. Under what circumstances may the elasticity of its sac be shown? How can blood discs pass through pores smaller than themselves?

cells. Their form is circular: they have a central depression, but no nucleus.

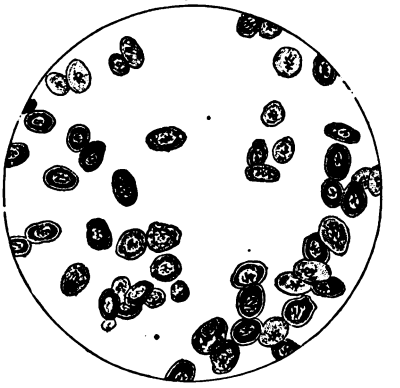
Fig. 32 represents the elliptic nucleated blood-cells of the frog, with here and there, at *a a*, chyle corpuscles. *Fig.* 33 represents the endosmotic action of water on these cells. *Fig.* 34 (page 98), the action of acetic acid in darkening or concentrating the nucleus. In *Fig.* 35 (page 98) we have an illustration of the size and appearance of the blood-cell in a reptile, the photograph from which this figure was taken having been made under the same magnifying power as that employed in obtaining the photograph of human blood.

Fig. 32.



Elliptic blood-cells of frog magnified 250 diameters.

Fig. 33.

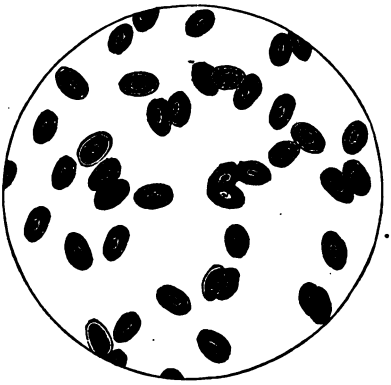


Action of water on elliptic cells.

The cell wall of the blood-cells is generally admitted to be fibrin, or some substance allied thereto; but there has been much difference of opinion respecting the constitution of the nucleus of those cells which possess it. By some, this also has been regarded as fibrin; by others, as fat; and by

What is the action of water and acetic acid on them? What is the nature of the cell wall of discs?

Fig. 34.



Action of acetic acid on elliptic cells.

Fig. 35.



Reptile blood-cells magnified 500 diameters.

others as a species of horn, to which the designation of nucleine has been given.

The cell wall of the white corpuscles does not appear to be elastic. It is viscid, and hence these bodies tend to agglutinate to one another: in aspect it is granular. The contents appear to be an albuminous solution, in which fine granules are suspended.

Though we have described the mesenteric glands as the original place of formation of the blood-cells, it is to be understood that these become perfected in the circulation of the blood; and from what will be said respecting the function of the liver, it may be inferred that that gland is the seat of a most important change: there probably they receive their iron. That no special organ is exclusively charged with the duty of forming them appears from this, that the first form of blood-cells arises in the germinal area of the embryo when there is, as yet, no gland.

Leaving the water out of consideration, the predomi-

Is the cell wall of the white corpuscles elastic? What connection does the liver seem to have with the discs?

nating ingredients of blood-cells are globulin and hæmatin. The former is a substance approaching, in properties, to casein, or perhaps intermediate between casein and albumen.

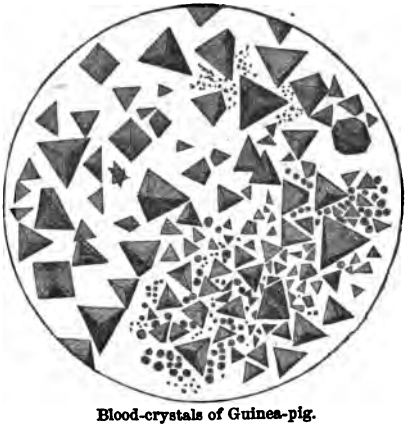
Hæmatin is distinguished by its red color. When isolated, it exhibits the changes of tint characteristic of arterialization in a doubtful manner. There are, however, some facts which lead to the supposition that the color of arterial and venous blood does not depend so much on a chemical change in the hæmatin as on an alteration of the figure of the discs. Hæmatin contains about 7 per cent. of iron.

Fig. 36.



Human blood-crystals.

Fig. 37.

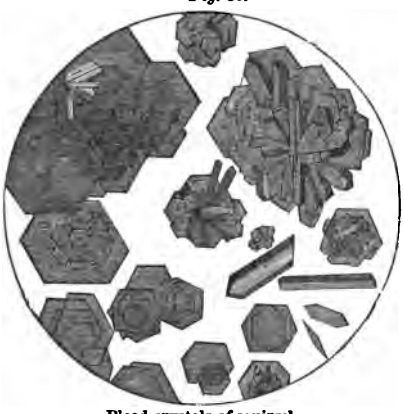


Blood-crystals of Guinea-pig.

The crystalline substance of blood occurs under three different forms, in prisms, tetrahedra, and hexagonal tablets. In the prismatic form it is derived from human blood, that of fishes, and of some mammals;

To what substance is globulin related? What are the properties of hæmatin? Under what forms may the crystalline substance of blood be obtained?

Fig. 88.



Blood-crystals of squirrel.

in the tetrahedral form it is obtained from Guinea-pigs (*Figure* 37), rats, and mice; in the hexagonal form from squirrels. Blood-crystals are of a red color, without smell or taste, losing their water of crystallization under exposure to the air, the different forms presenting different rates of solubility.

The crystals may be obtained for examination by covering a minute drop of blood with a glass slide, and, after adding water, alcohol, or ether, to permit a gradual evaporation to ensue.

The color of the blood, as dependent upon the tint of its cells, is asserted to be connected to a considerable degree with the form of those organisms as they vary from a concave to a convex surface, and not with the state of the hæmatin. When they are more concave they are of a crimson, when of a more convex, of a darker hue.

Among the causes which can impress a change on the figure of the blood-cells ought particularly to be specified exposure to oxygen and carbonic acid respectively, the latter causing them to become more opaque in their centre, broader upon their edge, the cell distending; an opposite effect ensuing under exposure to the former.

Constituted thus of an elastic sac filled with globulin and hæmatin, the cells float in the plasma. They are nourished at its expense, and when they die, deliver up their contents by deliquescence to it. Accompanying

Under what forms may the crystalline substance of blood be obtained? How is it that the color of the blood may depend on the form of the discs? What ensues under exposure to oxygen and carbonic acid respectively?

them are the white corpuscles, from which new generations are to arise. It is usually stated that for every 50 red discs there is one white corpuscle. They may be readily discovered during the circulation by the microscope, many of them occupying the exterior of the current, as though they had a special relation to the soft tissues.

We have next to speak of the plasma. It may be described as a clear and slightly yellowish colored fluid, consisting, as all animal juices do, for the most part of water, holding in suspension or solution albumen, fibrin, fats, and various mineral bodies.

Of the water it may be remarked, that the usual percentage estimate made of its quantity, as regards the entire blood, is from 700 to 790 parts in 1000. Within these limits it is liable to rapid variations, as dependent on the condition of thirst or the recent indulgence in drinks. It does not increase in proportion to the amount which has been imbibed, for the Malpighian bodies of the kidney, as will hereafter appear, strain it off with great rapidity. When the blood-vessels are distended to a certain degree, they refuse an entrance to it. The necessity of these provisions arises from the fact that there is a certain state of viscidity the blood must possess for its proper circulation.

The albumen varies in quantity from 60 to 70 in 1000. It is probably associated or combined with soda. It exists in the blood of the splenic and hepatic veins as the neutral albuminate of soda. It is the plastic material from which all the soft tissues are nourished, and by it the cells themselves grow. Fibrin arises from it in the blood in the same manner as it does during the incubation of an egg; every care is taken to economize it in the system, and it is never excreted except in disease.

The quantity of albumen is greater in venous than in arterial blood, the proportion increasing during digestion. It also presents variations in different states of disease. Its condition varies in various parts of the cir-

What is the relative number of the red cells and white corpuscles? Where do the latter chiefly occur in the blood current? What is the composition of the plasma? To what extent may water vary in the blood? How is its quantity diminished? What is the relative quantity of albumen? To what extent does it vary?

culation, a circumstance, to a considerable extent, due to the nature of the salts, or to the quantities of alkali with which it is associated.

The fibrin is usually estimated at 2 or 3 parts in 1000 of blood. It may fall as low as 1, or rise as high as 7½. There is a constant drain upon it for the nutrition of the muscular tissues; and since it originates in the action of oxygen upon albumen, we should expect, as is really the case, that arterial blood would be richer in it than venous. The portal blood contains it in minimum quantity. Its percentage rises if oxygen be inhaled, or the respiratory process be quickened; for similar reasons, it uniformly increases in acute inflammations.

It has been asserted, as was mentioned before, that there is so wide a difference between the fibrin of blood and muscular fibre, that we can no longer regard the latter as arising from the former, but must consider it merely as coagulated albumen; and that, since the action of acetic acid upon it shows its relation to gelatine, it is probably more nearly related to the fibro-gelatinous than to the cellulo-albuminous tissues. But, although the fact that fibrin contains more oxygen than albumen seems to lend weight to such views, since oxidation appertains to the retrograde rather than to the ascending metamorphosis, there are so many arguments in favor of the old doctrine, that I think it may be regarded as thus far unshaken. Moreover, it is now established beyond any doubt that by nitrate of potash, and other salts, fibrin may be transmuted into a substance analogous to albumen.

The fats vary very much in quantity at different times. The amount is usually stated at from 1.4 to 3.3 in 1000 of blood. After a meal the plasma may be actually milky, through the fat globules brought in by the chyle. We have already shown that starch will give origin to fat, and oily substances can be obtained from lactic acid itself. The nitrogenized bodies, during their destruction, likewise yield them, and it is a normal function of the liver to effect the production of fat.

What is the quantity of fibrin? What is its proportion in different kinds of blood? What reasons are there for supposing that fibrin is a histogenetic body? To what extent do the fats of the blood vary?

Among the special constituents of certain portions of the venous blood sugar ought not to be overlooked. It exists as a constant ingredient of the blood contained in that part of the circulation intervening between the liver and the lungs. As liver-sugar it may have originated in the transmutation of cane-sugar, or from the metamorphosis of the muscular tissues.

The mineral constituents of the blood discharge very different duties, some, either directly or indirectly, acting functionally, others as histogenetic bodies. Thus the alkaline properties of the blood are due to the presence of the carbonate and phosphate of soda, and this latter substance enables the serum to hold in solution carbonic acid, and thus it maintains a relation in the respiratory operation. But the phosphate of lime discharges a true histogenetic function, since upon it the bony system depends for its nutrition. The mutual relations of these substances are, of course, very complex, though often of importance. Thus, of the two just mentioned, the phosphate of soda enables the serum to hold the phosphate of lime in solution.

The gases which can be disengaged from the blood are carbonic acid, oxygen, and nitrogen. This liquid can absorb once and a half its volume of carbonic acid, and in arterial blood the proportion of that acid to oxygen is as 16 to 6, in venous as 16 to 4. That the oxygen is very loosely retained is shown by the circumstance that it may for the most part be removed by exposure in a vacuum. The other gases may be withdrawn by a stream of hydrogen.

At a temperature of 98°, water absorbs scarcely one per cent. of its volume of oxygen gas, but the blood can take up from 10 to 13 times as much. This is accomplished by the coloring material.

The preceding examination of the special constituents of the blood leads us next to consider the general functions of this liquid in the aggregate.

In this general sense, the blood discharges the following offices. Its albumen has the duty of giving origin

In what part of the circulation does liver-sugar occur? What are the chief mineral constituents of the blood? What are their functions? What gases may be disengaged from the blood? What is the relative absorption of oxygen by water and by blood?

to all the plastic tissues of the system. From it, for example, by cell action, as explained in treating of lacteal absorption, fibrin arises—fibrin, which is used for the renovation and repair of the muscular tissues. The discs have a relation with the function of respiration; they obtain oxygen in the pulmonary circulation, and carry it through the system. They contribute, moreover, to the development of muscular fibre, and also nervous material, and this not alone as regards the coloring matter of those tissues. The fats are necessary in the production of fibrin and for the nuclei of cells; but, besides these histogenetic relations, they eventually, with the exception of liver-fat, undergo oxidation, and so minister to the support of a high temperature. Of the saline substances, common salt promotes digestion by aiding in the preparation of gastric and pancreatic juices; the phosphate of soda enables the plasma to hold carbonic acid in solution, and carry it to the lungs.

It is interesting to observe the limits of variation the blood may present in disturbed or diseased conditions. In inflammations, the fibrin may increase fourfold; in typhoid fevers it may diminish to less than one half, and from these variations special results may arise. Thus diminution of its fibrin disposes the blood to preternatural oozing or facility of escape. So also the discs have been known, in cases of chlorosis, to sink to one fifth of the healthy amount. The albumen, too, exhibits like variations. In Bright's disease it greatly diminishes, much of it escaping in the urine by the straining action of the kidneys.

The discs are necessary to the production of a high temperature by constantly transferring oxygen from the cells of the lungs to every part of the body; carriers of oxygen they have been truly called. That this is one of their duties has been proved experimentally, for a solution of albumen or the serum has but little power of absorbing oxygen, scarcely exceeding water itself in that respect, but the discs condense it at once. The change of color they exhibit as they alternately gain or lose that element is in itself a proof of this fact, as is also the ac-

What are the general functions of the blood? To what extent may its composition vary in states of disease? How are the discs connected with the production of heat?

tion of serum or blood-discs respectively on a measured volume of air contained in a jar. If the discs be in the venous or purple condition, they quickly absorb oxygen from the confined air, which therefore at once diminishes in amount, but the serum, or a solution of albumen, produces no such effect. The plasma serves, therefore, for the general nutrition of the system, and the discs, by transferring oxygen from point to point, discharge that part of their duty connected with the production of heat.

But the discs, though of a flattened form, are truly cells, and all that obtains in the case of cell life and cell action obtains for them. They have not a duration at all comparable to the duration of the system, but are constantly coming into existence and disappearing. Each is an individual having its own particular history, its time of birth, its time of maturity, its time of death. Each passes through a series of incidents proper to itself. Originating as has been described, they grow at the expense of the plasma, and in this regard it serves for their nutrition as well as for that of the body generally.

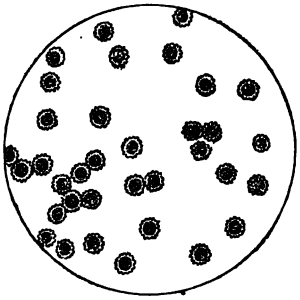
On exposing blood-cells to oxygen and carbonic acid gases alternately, there is not only a change in their shape, which becomes corrugated and star-like, but also in their chemical constitution, so that, eventually, they are entirely destroyed. Such alternations occurring in the system doubtless lead to the same result, though more slowly, since the oxygen is presented in a diluted condition.

The corrugated and star-like blood-cells abound in the blood of the portal, though not in that of the hepatic vein. If their appearance arises from their tendency to disintegration, this is no more than might be expected in view of the functions of the liver. That the stellated aspect is an indication of a commencing disorganization, or other profound change, may be illustrated by an examination of the action of water on normal blood-cells, which, if they be exposed to that liquid, undergo

What is the duty of the plasma and the discs respectively? In what particulars may the discs be considered as individuals? Under what circumstances may they become corrugated? What is the action of water upon them?

a distention; their thickness increasing more rapidly than their diameter, they lose their concavity, become convex, and at last appear as spheres of a less size than the original discs. When the quantity of water they have received has distended them to their utmost capacity, they are invisible; but when it is withdrawn from them by establishing exosmosis through the addition of saline substances, they may reappear in the corrugated or star shape, as seen in the photograph, *Fig.* 39.

Fig. 39.



Stellated blood-cells magnified 500 diameters.

With respect to the action of the hæmatin, it may be observed that other nitrogenized coloring materials present a similar relation to oxygen. As an example, indigo may be mentioned. I consider that the properties of this substance illustrate in a significant manner the properties of hæmatin in the system. Indigo occurs in the leaves of the plant which yields it, in a yellow and soluble state. It is easily extracted from them by maceration in water. Exposed to the air, it absorbs oxygen, becomes insoluble, and simultaneously gains a deep blue tint. So lightly is the oxygen thus united to it, that by exposure to very feeble agents it surrenders it up, and repasses into the yellow and soluble condition. Once more exposed to the air, it turns blue, and once more may have that color removed from it by taking its oxygen away. For many times in succession its tint may be thus changed, and made yellow or blue at pleasure.

From this we perceive in what a loose manner oxygen is held by such a coloring material; how readily it surrenders it, and how readily it recovers it. Such a union can scarcely be called an oxidation or a combination; it is rather an association.

All this is precisely what occurs in the case of hæmatin. It takes up oxygen with rapidity as it goes over

What are the changes in color which indigo may exhibit? What analogy is there between that substance and hæmatin?

the cells of the lungs, and turns scarlet; it surrenders that oxygen with equal facility as it passes the systemic capillaries, and turns blue. This change of color is incessantly taking place; it is now red and now blue, as the discs are passing in the greater and the less circulation.

Formerly it was supposed that, in the act of respiration, oxygen from the air united with carbon of the blood of the cells, and carbonic acid formed, a combination or perfect oxidation taking place in the lung. But, if this were true, the temperature of those organs should be higher than that of the rest of the body, and this is by all admitted not to be the case.

The discs are therefore carriers of oxygen. They receive that vivifying principle as they move over the respiratory cells, and, freighted with it, pass to all parts of the body, not united with it, nor disorganized, nor burnt up by it, but holding it loosely, and ready to give it up and go back again for a fresh supply.

The sac containing the hæmatin offers no kind of resistance to these exchanges. It will be fully demonstrated in the chapter on respiration that this is the case. Thick pieces of India-rubber, stout animal membranes, or even masses of stucco, present no obstacle to the passage of gases. The delicate wall of these cells, a tissue of almost inconceivable tenuity, can offer no resistance. The gas passes in and out without impediment or restraint.

But though in this manner these little organisms perform their duty, it is only for a time. They may take oxygen from the air-cells and give it up in the system, and do this perhaps many thousand times, but it comes to an end at last. The incessant motion stops, and the worn and exhausted disc is brought to its term. By degrees, as old age steals over it, it becomes corrugated and relaxed, is unable to withstand chemical reagents, as its younger comrades can do. Through the microscope it seems puckered and attenuated. The red color of its interior deteriorates into a tawny tint. As with

How is it known that hæmatin is not oxidized in the lungs? Why are the cells designated carriers of oxygen? Does the sac offer any resistance to the reception of oxygen? What eventually becomes of them?

a leaf in the autumn, the natural color of which disappears, and yellowness or other change precedes its fall, so with the dying disc. Unable any longer to discharge its duties, its existence is brought to a close, the decayed hæmatin is shed out, and gives a transient tawny tint to the plasma, but is presently strained off as one of the constituents of bile by the liver. Nor is this illustration wholly metaphorical, for, in the case of herbivorous animals, Berzelius has shown that the coloring matter of their bile is identical with chlorophyll, the coloring matter of leaves.

CHAPTER VIII.

OF THE CIRCULATION OF THE BLOOD.

The Heart as a Machine.—Inadequacy of Harvey's doctrine of the Circulation.—Physical Principle of the Circulation; applied in the case of a Nucleated Cell, Pervious Tissue, Motion of Sap and of Blood.—Dependence of the Circulation on Respiration.—Forms of Circulation: Systemic, Pulmonary, Portal.—Description of the Heart; its Movements.—Their Force, Number, and Value.—Sounds of the Heart.—Cause of its Contractions.—Description of the Arteries, Capillaries, Veins.—Explanation of the Circulation of the Blood.—Facts supporting it.—The First Breath.

No function of the animal mechanism illustrates more strikingly the doctrine that we must rely on physical agents for physiological explanations than that we have now to consider, the circulation of the blood.

We surrender some of the most beautiful recollections of classical mythology, and some of the most cherished popular illusions of our own times. The heart, which in the higher classes of life is the central organ of impulse of the circulation, is to be degraded into a mere engine. We have to speak of its valves, its cords, its pipes. We have to consider its exhausting and its forcing action—to deal with it just as we should deal with any hydraulic apparatus. In the old times this or-

gan was looked upon as the seat of the thoughts and the passions; it was the centre of all good and evil, purity and uncleanness, devotion and love. In the modern system the brain has succeeded to the functions once imputed to it.

The heart, then, is no longer an altar on which flames are burning, no longer the seat of the passions and the source of love. It is a machine, but what kind of a machine? How great is the admiration we may express at its exquisite construction! This little organ can execute three thousand millions of beats without a stop! In the course of a life, such as we sometimes meet with, it has propelled half a million tons of blood, and, though momentarily wasting, has repaired its own waste all the time. The mathematical rhythm of its four moving cavities, the perfect closure of its mitral and semilunar valves, and the regurgitating play of its tricuspid, have never failed it. To the eye of the intellect there is nothing lost in transferring it from the regions of metaphor and speculation to the domain of physical science.

The doctrine of the circulation of the blood was first propounded by HARVEY about two hundred years ago. It originated in the discovering of the valves of the veins by Fabricius ab Aquapendente. After many years of discussion, it was reluctantly received by the medical profession.

In this doctrine the circulation is referred to causes that are purely mechanical, in the strictest acceptation of that term. The contraction of the walls of the heart propels the blood through the arterial tubes, and even through the veins, the direction of its movement being insured by a proper arrangement of valves.

But when comparative anatomy and physiological botany were more extensively cultivated, it was seen that this doctrine is insufficient, for the unity of nature forbids us to believe that nutritious juices are circulated in different tribes of life by different forces. And though it may be that the contractions of that central impelling mechanism regulate the circulation in those organisms

What conception have we to entertain of the uses of the heart? By whom was the course of the circulation determined? Who discovered the valves in the veins? What is the function of the heart in Harvey's doctrine?

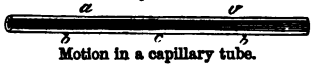
which have a heart, what is to be made of those countless numbers having none? In this group we find the whole vegetable creation, and a majority of the animal.

There is a physical principle that has long appeared to me sufficient. Its use in an explanation of the motion of nutritive juices in organized systems of every class I have taught in the University for many years. It possesses the advantage of generality, since it is applicable in every case, from the circulation taking place in a closed cell up to that of man.

In Chapter VI. is a general statement of the phenomena and laws of capillary attraction; the principle now to be employed is closely connected therewith. It may be stated as follows:

If two liquids communicate with one another in a capillary tube, for the substance of which they have affinities of different intensities, movement will ensue: the liquid having the highest affinity will occupy the tube, and may even drive the other before it. The same effect will ensue in a porous structure.

Fig. 40.



Motion in a capillary tube.

Thus, let *b b*, *Fig.* 40, be a capillary tube of any kind, occupied conjointly by two liquids, *a* and *v*, meeting each other in the middle, *c*; *a* having a high and *v* but little affinity for the substance of which the tube consists, *a* will occupy the tube, pressing out *v* before it. Of course it is to be understood that the liquids *a* and *v* respectively communicate with reservoirs that can furnish them a necessary supply.

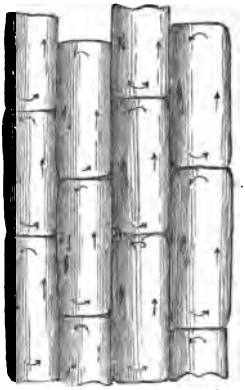
The various phenomena described under the designation of endosmosis are experimental illustrations of the same kind. Thus, when water is put on one side of a piece of bladder and alcohol on the other, the water, having the highest affinity for the substance of which the bladder consists, occupies the pores thereof, and expels the alcohol. Nor would any of the latter substance find its way in the opposite direction, back into the water, were it not so soluble or diffusible in that liquid. Exosmosis therefore takes place through the water, and constitutes a subordinate or feeble current.

On what physical principle does the capillary circulation depend? How does that principle explain endosmosis?

Now it is precisely relations of this kind that are observed in the case of the circulating and nutritive juices of all organic beings.

The simplest instance is presented by the fluid contents of certain nucleated cells, both among animals and plants, in which a current moves toward, and then from the nucleus, coming back in a returning path. The fluid which the cell contains yields to the nucleus, in which seems to be concentrated all the activity of the organism, the nutritive material it requires, and, this done, passes on to make way for other portions. The act of nutrition, therefore, is followed by motion, and this upon the above simple principle; for the liquid, before it approaches to the nucleus, is charged with material which the nucleus can attract; but immediately after contact has taken place, and the material has been removed, the liquid maintains no longer any relation with the nucleus, the affinity or attraction is satisfied, and, so to speak, it loses its hold thereupon, and is pressed off by new-coming portions. Before its approach, and after its departure, the liquid has opposite relations to the nucleus, and in this respect may be regarded as representing two liquids, the one having a high affinity, and the other none, for the nucleus. The circulation in vegetable cells is shown by the direction of the arrows in *Fig.* 41. The course taken by the current may be determined under the microscope by the minute floating, or, rather, drifting granules. It is to and then from the nucleus.

Fig. 41.



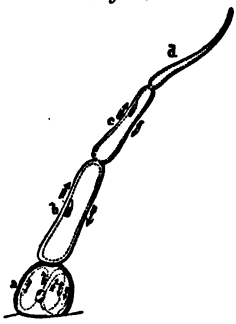
Circulation in vegetable cells.

Fig. 42 (page 112) represents one of the jointed hairs from the Tradescantia Virginica. *a*, *b*, *c*, *d* are the successive cells of the hair. The dotted lines show the direction of the current to and from the nucleus.

The juice about to nourish a part has for that part a

Under what circumstances does circulation take place in cells? Describe the illustrations, *Figs.* 41 and 42.

Fig. 42.



Circulation in Tradescantia.

certain affinity, but, with the accomplishment of that nutrition, the affinity is at once lost. Thus, for instance, in the systemic circulation, the parts to be nourished have a certain affinity for arterial blood; they take from it whatever their purposes require, and, that done, the relation at once ceases; the blood, become venous, has lost its hold upon them, and is pressed off. We may conveniently describe this effect as a pressure of the unchanged upon the changed liquid.

The motions of the sap in plants are clearly dependent on this principle. Leaving out of consideration the minor movements taking place for special purposes, or at specific epochs in the development, it may be truly said that the nutritive changes occurring in the leaf are the primary cause of the motion; for, as the ascending sap presents itself on the sky face of the leaf, it receives carbon, under the influence of the sunlight, from the air, and becomes converted into a gummy, glutinous liquid. And just as in the pores of a bladder, or in those of any pervious mineral, pure water will drive out gum-water, and occupy the pore, so will the ascending sap expel the gummy solution from the capillary tubes or intercellular spaces of the leaf. As fast as this takes place, the active liquid becomes inactive, by itself changing into a gummy solution, and the movement is perpetuated. And this ensues not only in the leaf, but in every part of the plant; the liquid to be changed presses upon that which has been changed, and forces it onward. In this manner, motions in various parts and of very great intricacy will ensue, but all of them, if duly considered, no matter whether their seat be in the root or in the bark, in the flowers or in the leaves, no matter whether they take place in the height of summer or just at the close of winter, when the sap first rises, or even in the germinating seed which is under the ground, and has never

What is the explanation of the motion in those cases? Give the explanation of the flow of sap.

yet been exposed to the light, may, without difficulty, be referred to the nutritive change carried on in the leaves of the plant under examination, or its parent, by the influence of the rays of the sun.

All this holds good, not only in the nutrition of a cell, the more complicated nutrition of the various parts of a flowering plant, or even of an animal, but likewise in those destructive changes restricted to the latter class, and arising in interstitial decay; for the blood has a double duty to perform: it not only serves for nutrition, but also for the removal of effete and dying parts. These it effects the oxidation of, their carbon passing into carbonic acid, their hydrogen into water; and this is accomplished by oxygen obtained in the process of respiration. The scarlet or arterial blood, charged with its oxygen, passes to all parts of the economy in search of organic particles ready to be removed; it effects their disorganization, and, becoming thereby venous, is pressed onward. And now, if we recall that nutrition in animals depends on the access of air—even fibrin can not arise from albumen except under that condition—we can not avoid the conclusion that all operations of repair and all operations of waste are made to conspire together for the production of movement; and though every part offers its own special cause, as depending on nutrition, or disintegration, or secretion, they may be all grouped together as the necessary results of one more primitive operation, the supply of oxygen to the blood in the respiratory mechanism.

In my view of this subject, it is therefore the arterialization of the blood in the lungs which is the cause of the circulation in man. I consider the circulation as the consequence of respiration; and though, in one sense, the minor causes are numerous, each portion of nervous material, each muscular fibre, every secreting cell working its own way, these subordinate actions are all referable to one primordial act, and that is the exposure of the blood to the air.

Whatever, therefore, interferes with respiration, interferes with circulation. If an irrespirable gas is thrown into the cells of the lungs, the passage of the blood is

Explain upon the same principles the capillary circulation of animals. How is it that the circulation is connected with respiration?

instantly arrested, and asphyxia ensues. Or, if the access of the air is cut off, as in drowning, in vain the heart exerts its utmost convulsive throb—it is unable to drive forward the blood; and in those cases, by no means infrequent, yet undoubtedly the most surprising occurring in the practice of medicine—restoration from death after drowning, the whole success turns on one condition, the re-establishment of the arterialization of the blood. If that be accomplished, the circulation is restored, and the heart proceeds with its duty. And for these reasons, I believe that in many cases success would be had, where failures are now experienced, if, instead of resorting to atmospheric air, pure oxygen gas or protoxide of nitrogen were administered.

In the more highly-developed organisms the objects of the circulation are threefold: 1st. To minister to the nutrition of the system; 2d. To introduce oxygen; 3d. To remove the products of waste. In man, these various results are accomplished by several different arrangements: 1st. The greater, or systemic circulation; 2d. The less, or pulmonary circulation; 3d. The portal circulation; 4th. The Malpighian circulation, etc.

The course taken by the blood is as follows. Leaving the left ventricle of the heart, it passes into the aorta, and is distributed by the ramifications thereof, constituting the systemic arteries, to all parts of the system. It moves onward through the capillaries, which may at once be considered as the terminal ramifications of the arteries and the commencing tubelets of the veins. These, converging into larger and larger venous trunks, the systemic veins, deliver it into the ascending and descending venæ cavæ, from which it flows into the right auricle, and from thence into the right ventricle of the heart. From thence it is driven into the pulmonary artery, to be distributed to the lungs, and, coming therefrom along the pulmonary veins, reaches the left auricle, and from thence it gains the left ventricle, which was its starting-point.

In the pulmonary veins, the left cavities of the heart,

What is the essential point in restoring the circulation after drowning? What are the objects of the circulation? What is the general course of the blood in the systemic circulation? What is it in the pulmonic?

and in the systemic arteries, the blood is crimson. In the systemic veins, the right cavities of the heart, and pulmonary artery and its branches, it is blue. The change from crimson to blue takes place in the systemic capillaries, and from blue to crimson in the pulmonary. The systemic, or greater circulation, is considered as beginning at the left ventricle and ending at the right auricle; the pulmonary, or less circulation, begins at the right ventricle and ends at the left auricle. This double course is sometimes illustrated by likening it to the figure 8, the upper loop representing the pulmonary, the lower the systemic circulation, the heart being placed at the nodal point.

As has just been remarked, there are other subordinate circulations, but of these only one need attract our attention at present—it is the portal. This originates in a system of capillaries, the veins belonging to the digestive apparatus, which, converging rapidly together, form a common trunk, the portal vein. This at once ramifies like an artery in the substance of the liver. From the resulting capillaries, the blood passes into the commencing capillaries of the hepatic veins, which empty into the inferior vena cava, and so it reaches the general circulation. The physical peculiarity of the portal circulation is, that it commences in a capillary system, and ends in one, without the intervention of any central organ of impulse, or heart. At a very early period, comparative anatomists were struck with the analogy between the portal circulation in man and the systemic circulation of fishes, both being carried on in the same way, that is, without a heart. In fishes, the heart is a branchial, respiratory, or pulmonary one. Their systemic circulation, or circulation of crimson blood, commences in the capillaries of the respiratory apparatus, the gills; a convergence takes place into an aorta, which ramifies into systemic capillaries. So the great circulation in these tubes is accomplished without any heart. It is scarcely necessary to point out the bearing of such a fact on the theories of the movement of the blood.

In *Fig.* 43 (page 116) is a diagram of the circulation

Where is the blood crimson, and where blue? What is the portal circulation? What is its physical peculiarity? In what respect does the portal circulation resemble the systemic of fishes?

Fig. 43.

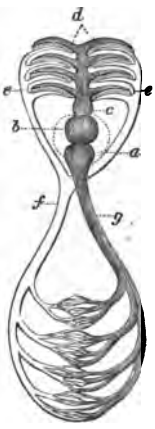


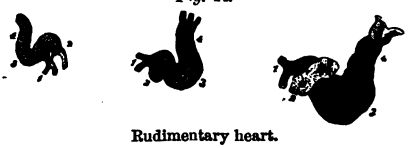
Diagram of fish circulation.

of a fish; *a* is the auricle; *b*, the ventricle; *c*, the branchial or pulmonary artery; *e*, *e*, the branchial or pulmonary veins, bringing blood from *d*, the branchiæ, and converging directly to *f*, the aorta, which distributes the systemic blood. This is collected into a vena cava, *g*, and so brought to the auricle, *a*. There is, therefore, no systemic heart.

The farther discussion of this subject will be continued as follows: We shall describe, 1st, the construction and action of the heart; 2d, of the arteries; 3d, of the capillaries; 4th, of the veins. We shall then present a view of the combined result of these various mechanisms.

1st, THE HEART. The first appearance of the heart is as a cavity arising in a collection of cells by deliquescence or separation of the central ones. At this early period, and even before the cavity has fairly formed, pulsation may be observed. The organ soon assumes a tubular form; and this, becoming curved, as shown in *Fig.* 44, differentiates into three compartments, with arterial and venous connections; 1, the venous trunks; 2, the auricle; 3, the ventricle; 4, the bulbus arteriosus. The form to be eventually assumed is foreshadowed in the manner in which the curved tube develops, the arch of the curve, 2, bulging so as to form a conical ventricle. This trichambered heart remains permanent in fishes, as seen in the preceding figure (43), of which *c* is the third chamber. But in birds and mammals, the aortic bulb merges into the ventricle, through which, as well as through the auricle, a septum or partition is established, and thus a double heart, or one of four chambers, arises.

Fig. 44.



Rudimentary heart.

Describe *Fig.* 43. What is the mode of development of the heart?

The diagram, *Fig.* 45, represents a double-chambered heart, *d* being its auricle, *e* the ventricle, *c c*, the veins converging to the auricle, *a* the aorta or main artery passing from the ventricle. The course of the blood is indicated by the arrows.

Fig. 45.

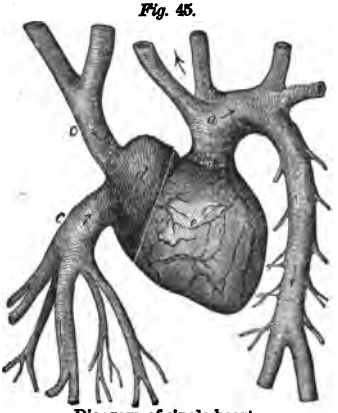
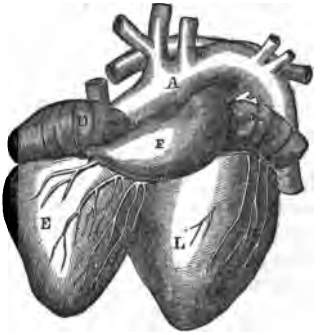


Diagram of single heart.

The heart with four cavities may be considered as arising from the conjunction of a pair of the preceding form, with their efferent and afferent tubes, or arteries and veins, so modified or arranged that the right heart receives its blood from the system in an auricle, from which it passes into a ventricle, and thence to the lungs. From the lungs, after aeration, this blood is brought to the auricle of the left heart, thence into its ventricle, and thence to the aorta. Though all four chambers are generally coalesced into one conical form, the heart of the dugong, *Fig.* 46, presents the true typical structure; E is the right or pulmonary ventricle, L the left or systemic ventricle, their apices being quite apart; D is the right or systemic auricle, F the pulmonary artery, K the left or pulmonary auricle, and A the aorta.

Fig. 46.



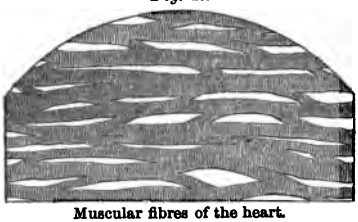
Heart of the dugong.

Externally, the heart is covered by a serous mem-

Describe the diagram, *Fig.* 45. How may the four-chambered heart be considered as arising? What is there peculiar in the heart of the dugong?

brane, pericardium, and in its interior is sheathed by the endocardium, an extension of the interior coat of the great blood-vessels. Though its movements are wholly involuntary, its muscular fibres are of the transversely striated kind. They are about one third less in diameter than those of voluntary muscles generally, and are especially characterized by their disposition to anastomose with one another, as represented in *Fig.* 47. In the ventricles the arrangement is such that the fibres of the external and internal surfaces decussate.

Fig. 47.



Muscular fibres of the heart.

The motions of the heart consist in the dilatations and contractions of the muscular walls of its cavities. The two auricles contract at the same moment, as do also the two ventricles, but the contractions of the auricles coincide with the dilatations of the ventricles.

The course of the blood through the heart is this. The venous blood, brought by the ascending and descending cavæ, flows into the right auricle as it is dilating, and for the moment pushes forward to the ventricle, but the auricle, being of less capacity than the ventricle, is filled to distention first; at this instant it contracts, forcing its contents past the tricuspid valve into the ventricle, and fills it completely. The blood can not regurgitate into the veins to any extent while this is going on, because of the almost perfect closure of their valves. The right ventricle now commences to contract; its fleshy columns shorten so as to pull upon the tendinous cords attached to the flaps of the tricuspid valve: this enables the blood to get behind them, and they quietly close the aperture between the auricle and ventricle; the closure is not, however, under all circumstances, perfect, the mechanism being such as to permit leakage or regurgitation to a limited extent. The blood

What is there peculiar as respects the muscular fibres of the heart? In what order do the dilatations and contractions of the auricles and ventricles take place? Describe the course of the blood through the heart.

now rushes into the pulmonary artery, passing by its semilunar valves, which, the moment the ventricular pressure ceases, shut, so as to prevent any return to the heart.

Having passed through the lungs and been submitted to the air, the blood now returns to the left auricle, and is forced by it into the left ventricle, the action on this side of the heart being the same as on the other; the mitral valve, closing the opening from the auricle into the ventricle, is worked in the same manner as the tricuspid, and the blood is pressed into the aorta, the semilunar valves of which, at that instant, shut abruptly with an audible sound, and prevent any regurgitation. In this manner the distribution to the system is accomplished.

On both sides of the heart, as soon as the auricles have finished their contraction, they begin to dilate, and continue to do so during the period that the ventricles are contracting. Thus there is an accumulation in them when the ventricles are ready to dilate, and, as soon as that occurs, the blood flows freely forward into those cavities, the complete distention of which is then accomplished by the contraction of the auricles, as before explained.

The mode of action of the two sets of cavities is different. The auricles contract suddenly, first at the place of junction of their veins, the effect passing quickly forward; the ventricles contract more slowly, but simultaneously in every part.

During each beat of the heart two sounds may be heard, followed by a silence. The first sound is dull; the second, which follows it quickly, is sharp. They may be imitated by articulating the syllables lubb, dup. The first is due to the contraction of the muscular fibres of the ventricles, and the striking of the apex of the heart against the wall of the chest; to a certain extent, the opening of the semilunar valves, and the rush of the blood into the pulmonary artery and aorta contribute to it. The second sound is due to the shutting of the semilunar valves of the aorta and pulmonary artery.

Describe the manner in which its valves work. In what manner do the auricles and ventricles respectively contract? What sounds are emitted? What is the cause of these sounds?

At each contraction of the ventricles the heart strikes against the walls of the chest, usually between the fifth and sixth ribs, and an inch or two to the left of the sternum. This motion is partly due to the action of the spiral muscular fibres of the ventricles, which gives a tilt to the heart, and partly to the globular form the whole organ suddenly assumes.

The number of pulsations made by the heart differs very much at different periods of life: at birth it is from 130 to 140 per minute; at the seventh year, from 80 to 85; during mature life, from 70 to 75; and in old age, from 50 to 65. In females it is more frequent than in males. It observes a general relation to the number of respirations, five pulsations commonly occurring during one respiration. It varies with incidental circumstances. During sleep it declines in frequency; after eating, or during exercise, it is quickened. Examined from morning to evening, it becomes slower by degrees. Lying down, the pulse is slower; in a sitting posture, more frequent; and still more so when standing, the variations depending on muscular exertion. In conditions of disease, the ratio between the number of pulsations and respirations is variable.

The walls of the left ventricle are twice as thick as those of the right, and the force of its contractions is about double. The capacity of the two ventricles is nearly the same, and is taken at about three ounces. The active force with which the auricles dilate is feeble, and wholly incompetent to exert any thing like the suction power at one time supposed, yet that they are not distended by the mere influx of the blood is satisfactorily proved by their dilatation after the heart has been cut out.

With respect to the absolute force which the left ventricle exerts for the propulsion of the blood into the systemic arteries, it is stated to be 13 lbs. This result is derived from the consideration that the pressure of the blood in the aorta is about 4 lbs. 3 oz.

That the motions of the heart can not be referred to the presence of the blood, or any reflex action arising from the cerebro-spinal system, but must be attributed

What is the number of pulsations? How do they vary? What is the absolute force of contraction of the left ventricle?

to the organ itself, is proved by their continuance after its excision from the body, or even after it has been cut in pieces. Some have supposed that the minute sympathetic ganglia with which it is furnished are the source of the motive power; others are disposed to impute it to a self-contractile power of its muscular fibres, irrespective of any nervous agency. Of course, it is admitted by all that the brain and spinal cord can influence these movements, but such effects are superadded and not uniform.

Of these opinions, we shall find many reasons for preferring the first when we come to the description of the nervous mechanism. It will be then seen that one of the prominent functions of nervous ganglia of a certain order, and particularly the ganglia of the sympathetic, is the storing up of impressions they have received, and thus becoming reservoirs or magazines of force. The power thus engendered or contained in them is by no means always delivered out in totality at once, but it may be in small portions, at intervals, for a long time; and doubtless in this way the minute sympathetic ganglia of the substance of the heart retain a power of keeping up the motions of that organ for a certain period of time, even though great lesions or morbid changes may have supervened. Such a mechanism recalls the manner in which chronometers are kept going during the short time that the action of the main-spring is taken off when the watch is wound up.

2d. THE ARTERIES are tubes consisting of different tunics or layers variously numbered by anatomists. They may be sufficiently described as, 1st. The exterior tunic, containing fibres generally running lengthwise, connective and elastic tissue: it is of about the same thickness as the tunic below; 2d. The middle tunic, characterized by being composed of non-striated muscular fibres circularly arranged; 3d. The interior tunic, thin, and consisting of a cellular or epithelial layer, smooth and polished, to permit of the ready passage of the blood.

The elasticity of the arteries enables them to sustain the sudden action of the heart by distending to a certain

On what nervous influences do the motions of the heart depend? What is the mode of action of its ganglia? Of how many tunics are the arteries composed?

degree as the blood is driven into them, and by their gradual collapse when the ventricles cease their pressure, the jetting or intermitting flow is converted eventually into a continuous stream. The mechanical influence of the heart is thus decomposed into two portions: one, of momentary duration, or, at all events, lasting only so long as the ventricle contracts; and a second, occupied in distending the elastic arterial tube; but this portion is not lost to the circulation, since the tube, as it contracts, yields it back again to the blood. The momentary impulse of the heart is thus spread over a considerable duration without loss.

The muscularity of the arteries is shown by their contraction on exposure, their subsequent dilatation being due to their elasticity, this contractile property being continued for some time after death. It is also proved by the great diminution of diameter the arteries exhibit when under the influence of an electric current. The quantity of muscular and elastic tissue in different arterial tubes is usually in an inverse proportion. In the great arteries the elastic tissue abounds, in the smaller the muscular increases. By their muscular coat the quantity of blood in these tubes can, within certain limits, be regulated.

At each injection of blood into it an artery distends. It then contracts, and thus gives origin to a pulsation. Its increase is both in diameter and length, the tendency being to lift it at each pulsation. The distention does not occur at the same instant in all these tubes, but those nearest to the heart yield first, and the more distant a little later. There is, therefore, what may be termed a wave of distention passing throughout the length of each arterial tube, and another actual wave in the blood itself. These pass onward at different rates of speed. The interval of wave-motion from the heart to the wrist is about one seventh of a second. Of course this wave-motion is to be distinguished from the absolute movement of the blood, which is much slower. In the carotid artery the flow of the blood is about one foot in one second.

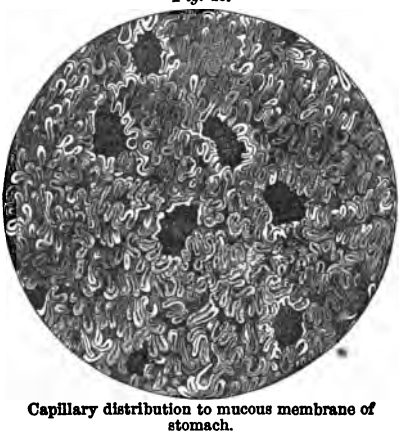
What is the effect of their elasticity? How may the muscularity of the arteries be proved? Describe the action of an artery as the blood flows into it. What is meant by the wave-motion?

A pressure or impact, communicated to a liquid in a long tube, is transmitted to the more distant end with vastly more rapidity than the liquid itself could flow through the same distance. Thus, if we were to suppose a very long metal tube to be filled completely with water, its two ends having been tightly closed by tying pieces of bladder over them, the tap of a finger on one of the pieces of bladder would be almost instantly felt by a finger laid on the other. Indeed, it has been proposed to establish telegraphic communication on this principle, though such attempts would prove abortive from the interference of collateral circumstances. This example may serve, however, to illustrate the essential difference between the flow of a liquid in a tube and the passage of a pulsation through such a liquid contained in such a tube.

3d. THE CAPILLARIES may be regarded as tubular continuations of the arteries and the commencement of the veins. They ramify through the organic structures. They are of pretty uniform diameter, and may therefore be looked upon as cylinders. Their usual size is about $\frac{1}{3000}$ of an inch; their mode of distribution varies with the structure and functions of the part they occur in: thus, in muscles they run parallel; in the papillæ they are looped.

They consist essentially of a delicate structureless membrane, analogous to cell membrane, and the sarcolemma of voluntary muscles. It possesses a certain degree of elasticity, and presents here and there cell nuclei.

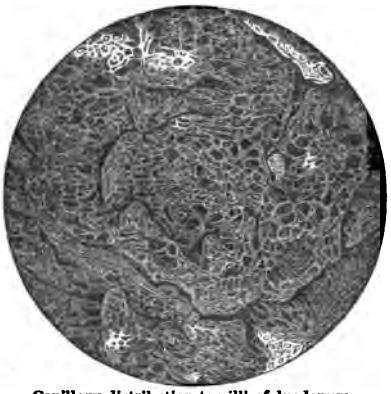
Fig. 48.



Capillary distribution to mucous membrane of stomach.

How may the impact of the blood be illustrated? Describe the capillaries.

Fig. 49.



Capillary distribution to villi of duodenum.

The interspaces between adjacent capillaries vary much in size and shape, the latter variation being dependent on the mode of distribution, whether parallel, reticulated, looped, etc.; as to size, in the liver the interspaces are of less diameter than the capillaries, in the choroid coat still smaller, but in the cellular coat of the arteries they are ten times larger than the vessels. These interstitial spaces are nourished by the matter exuding through the thin walls of the capillaries.

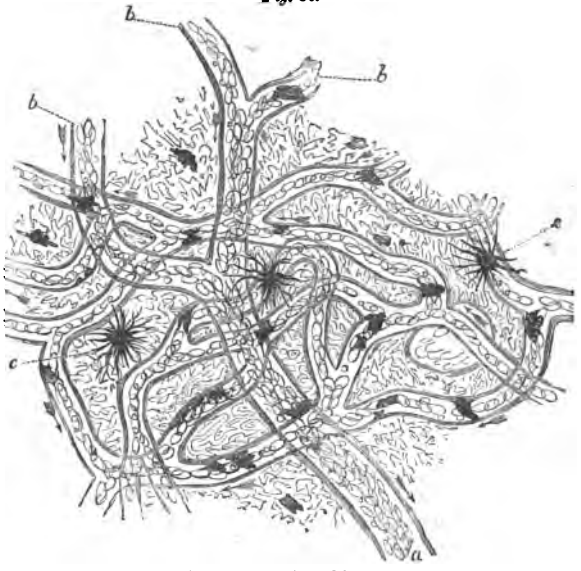
Fig. 50 represents the capillary circulation in the web of the frog's foot: *a*, venous trunk; *b b*, branches of venous trunk; *c c*, pigment cells. The elliptical blood-discs are seen in outline in the interior of the vessels.

The blood flows through the capillaries in an uninterrupted stream, its jetting motion being entirely lost. The rate of circulation through the systemic capillaries is about three inches per minute, that through the pulmonary being five times as swift, the length of the capillary tube to be passed $\frac{1}{30}$ of an inch, so that the passage from the artery to the vein may be accomplished in less than one second. It is to be remarked, however, that all parts of the cylindrical stream do not move with equal rapidity. Those parts nearest to the wall of the vessel are spoken of as the still layer, from their tardy movement. It is in this that the white corpuscles may be seen.

Fig. 51 shows a portion of a small vessel from a frog's foot: *a a*, red blood elliptic cells, occupying the axis of the vessel, and exterior to them, moving more slowly, or

How does their distribution vary? How are the interstitial spaces nourished? Does the blood move in a jetting way in the capillaries? What is the still layer?

Fig. 50.

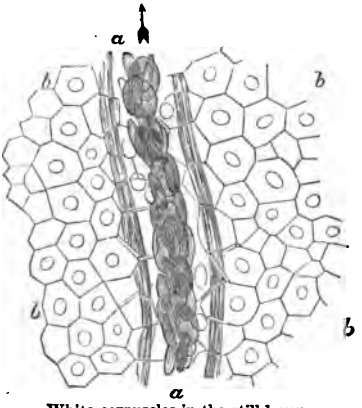


Capillary circulation of frog's foot.

occupying the still layer, the white spherical cells; *b b*, nucleated epithelium.

4th. THE VEINS have a structure in some respects different from that of the arteries. Their elastic coat is by no means so much developed, and their muscularity less distinct. With the exception of those of the lungs, abdominal viscera, and brain, their interior is furnished with valves of single,

Fig. 51.

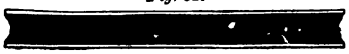


White corpuscles in the still layer.

Describe the structure of the veins. What veins have no valves?

double, or triple flaps, in all instances opening toward the heart. The blood flows equably in them, the pulsating action of the ventricles having disappeared in the capillaries. Since they present an aggregate capacity two or three times that of the arteries, the motion of the circulation in them is proportionably slower. *Fig.* 52 is a diagram showing the manner in which the valves open when the blood flows in the course indicated by the arrows. *Fig.* 53 shows their application to each other, or to the sides of the vein, and the consequent bulging of that vessel when the current, as indicated by the arrows, is in the opposite direction.

Fig. 52.



Valves of veins open.

Fig. 53.



Valves of veins shut.

Having now described the structure and action of the heart, the arteries, capillaries, and veins respectively, as far as is necessary, it remains to group those actions together, and present the theory of the circulation at one view.

But, before entering on this, it is proper to offer an argument against the doctrine of those physiologists who still maintain that the circulation is wholly dependent on the heart, and that that organ is entirely competent to carry it on.

The majority of the circulations we examine in organic forms are accomplished without any heart. Plants have none; fishes have no systemic heart; even in man, at the first period of embryonic existence, there is no such central organ; in his adult condition the portal circulation has none. The current of blood in the capillaries, seen under the microscope, exhibits no jetting movements, but, on the contrary, a steadiness of flow, sometimes for long in one channel, then a cessation, then perhaps a retrogradation, and then a new path. It looks as though the blood was flowing spontaneously, and not by any force acting behind. The heart of an animal

In what direction do the valves open? Does the action of the ventricles reach the veins? Mention some facts proving that the heart is not the sole cause of the circulation.

may be suddenly cut out, and yet the capillary motion may go on in the same direction as before. After death the arterial tubes are most commonly found empty: a result which is a mechanical impossibility on the supposition that the heart alone drives the blood, but a necessary consequence if the capillaries draw it. In acardiac monsters the blood circulates without difficulty, and, though it was at one time supposed that in these twins the hearted fœtus drove the blood through the heartless one, this is now demonstrated not to be the case. The circulation, moreover, varies locally, and at special epochs, as in the development of the generative organs, the mammary glands, the flow to the erectile tissues. Ubi irritatio ibi fluxus is an old medical aphorism, and these local variations are incompatible with the action of one central unvarying force. In cases of spontaneous gangrene, it sometimes occurs that the circulation through the part has declined; while the capillaries are all open, as subsequent examination proves. The application of cold to a part checks the circulation through it, and this not through any contraction of the vessels; so, likewise, does a jet of carbonic acid gas directed upon them. Moreover, any retardation in the supply of air to the lungs restrains the circulation, and this not alone in the pulmonary vessels, but also in the systemic capillaries, producing an increased pressure in the arterial tubes, a diminished one simultaneously occurring in the veins; and if, in the various cases now mentioned, the propulsive action of the ventricles can not be relied on to explain the difficulties, neither can any supposed suction or exhausting action of the auricles. When a ligature is tied round a vein, the action of the auricle is cut off, but the vein distends beyond the obstruction, showing that there is a force acting from the capillaries. Flexible tubes, such as those vessels are, would at once collapse under the exertion of a very moderate suction power, far less in intensity than would be necessary to draw the blood in the veins.

In spasmodic asthma, and in all pulmonary congestions, the right side of the heart circulates the blood

May the capillary circulation go on when the heart is removed? What is the effect of cold on the circulation? What is the effect of a ligature? What is remarked in pulmonary congestions?

with difficulty through the lungs, showing the existence of a great obstruction to its motion through the pulmonary capillaries. An examination of the condition of the various portions of the circulatory apparatus after death presents facts utterly inexplicable on the doctrine of the sufficiency of the heart. I have already mentioned the empty state of the systemic arteries; to this may be added what is often witnessed—the distended condition of the pulmonary artery, into which the blood has been forced by the expiring beats of the right ventricle, but has been unable to get through the pulmonary capillaries because of the cessation of respiration; but in other cases, where respiration has come to an end more tranquilly or slowly, the left auricle is full of blood, which must have been driven into it by the pulmonary capillaries. In sudden death, as by hanging and drowning, the right heart is excessively distended, as is also the pulmonary artery.

I might proceed to add to these other facts exhibiting local variations of the supply of blood in the periodicities of the system. There is a certain amount sent to the brain during the day, and a less during the repose of the night; in the muscular system, during the time of its action, the quantity demanded is greater; in its state of inactivity, less. A constantly and invariably acting machine, such as is the heart, could by no possibility adjust these variable supplies. But the cases here offered are more than enough, and it remains to be added that, though not one of them can be explained on the doctrine of the sufficiency of the heart, there is not one which does not follow as a necessary consequence of the doctrine now to be presented.

EXPLANATION OF THE CIRCULATION OF THE BLOOD.

On this view, the circulation is conducted in the following manner. The left ventricle of the heart impels the blood into all the aortic branches, any backward regurgitation into the auricle being prevented by the shutting of the mitral valve; the force employed is decom-

What is the usual state of the systemic arteries after death? What is the condition of the heart in hanging and drowning? Can the theory of the heart's action explain local variations in the blood supply? Describe the circulation as far as the heart's action extends.

posed into two portions, one part exerting an instantaneous effect on the blood in pressing it forward, and ceasing instantaneously, and thus giving origin to the pulse; the second distending the arterial tubes, but not being lost thereby, since their elasticity causes them to contract, and the semilunar valves at the origin of the aorta being at this period shut, a steady, onward pressure is exerted on the blood; so the quickly-ending action of the ventricle gives origin to two distinct mechanical results—a sudden impact and a continuous pressure. This suffices to bring the blood to the arterial origin of the capillaries, and beyond that point the action of the heart may be considered not to extend.

The relation between the interspaces of the capillaries and the blood thus introduced to them continues the current. The particular mode in which this relation is manifested differs in different parts. The oxidizing arterial blood has a high affinity for those portions that have become wasted; it effects their disintegration, and then its affinity is lost. The various tissues require repair; they have an affinity for one or other of the constituents of the blood; they take the material they need and their affinity is satisfied; or secreting cells originate a drain upon the blood, and the moment they have removed from it the substance to be secreted, they have no longer any relation with it. So processes of oxidation, and processes of nutrition, and processes of secretion all conspire to draw the current onward from the arteries, and to push it out toward the veins; and though these processes may present themselves in many various aspects, they are all modifications of the same simple physical principle.

The blood has now reached the veins, and is forced onward in them by the power that has thus originated in the capillaries. The influence of the heart is here unfelt, the exhausting action of its right auricle is inappreciable, and, thus pushed onward from the capillaries, it reaches the heart, completing its systemic or greater circulation. This circulation may therefore be said to be due to the high affinity which arterial blood has for the tissues, venous blood having none; and the action

Describe the cause of its circulation in the capillaries. Describe its circulation through the veins.

of the heart is confined to the filling of the arterial tubes, and presenting fresh portions of blood to the capillaries.

Arrived at the right auricle, the blood flows continuously into it and the right ventricle for a moment, but the ventricle holding more than the auricle, the latter cavity is fully distended first. At that instant it contracts, the valves in the veins shutting, and the blood, driven thus forcibly into the ventricle, distends it to the utmost. The ventricle, in its turn, now contracts, the tricuspid valve shutting, and the blood issues forth through the pulmonary artery, its valves then closing. At this moment an event occurs which, in these descriptions, is generally overlooked—an action analogous to that of the hydraulic ram. On the shutting of the tricuspid, the whole column of venous blood would be brought to a stop if the tubes containing it were unyielding, and a great force would be generated from this stopping of its momentum; but the auricle is ready to dilate, and into its cavity the blood, which would be otherwise checked, flows. I consider that this safety action of the auricle is one of its prime functions. The rapidity with which the dilatations and contractions are taking place furnish no argument against the occurrence of this action. I have a hydraulic ram, the pulsations of which may be so adjusted as to exceed greatly in frequency those of the heart, and, indeed, to give rise to a low murmuring sound, and yet, under these circumstances, the lateral force is so great as to throw a column of water more than forty feet high. If it were not for the dilatability of the auricles and their yielding texture, the veins would burst on the shutting of the tricuspid valve.

The ramifications of the pulmonary artery bring the blood to the capillaries of the lungs, but beyond that the influence of the heart is not felt, for now the physical principle heretofore described comes again into action. The venous blood has a high affinity for the oxygen of the air, an affinity satisfied as soon as the blood presents itself in the cells of the lungs. Arterialization being accomplished, the portions to be changed exert a pressure

Describe its passage through the right side of the heart. What is meant by the safety action of the auricle? Describe the circulation through the lungs.

on those that have changed, and the blood, moving forward in the pulmonary veins, reaches the left auricle of the heart.

For a moment it passes into the left auricle and ventricle continuously, but the auricle, being of less capacity, fills first. It contracts as soon as it is completely full, and drives its contents into the left ventricle, distending it to the utmost. The ventricle now contracts, shutting the mitral valve, and the ram-like action is repeated on this side of the heart. But the blood expelled from the ventricle is urged into the aorta, its force being decomposed, as before described, one part acting instantaneously as an impact on the blood, the other on the arterial walls, and on the first moment of the recession of the walls of the ventricle the semilunar valves of the aorta shut, and this act completes one tour of the circulation of the blood.

In this description I have said nothing of the circulation in the substance of the heart itself, since it would have led to a needless complication. It should be remembered, as an illustration of the working of the physical principle here explained, that the motion of the blood is contrary in the greater and less circulations, compared together. In the former, the current is from the crimson to the blue; in the latter, from the blue to the crimson side.

The action of the heart is therefore limited to the filling of the arterial tubes, so as to present to the capillaries a constant supply of blood. There seems to be but little suction force exerted by the auricular cavities for the emptying of the veins. The valvular construction of these vessels economizes every pressure that the muscles may exert on them in favor of the circulation, for every such pressure must, by reason of the valves, force the blood onward to the heart. This is, however, only an incidental result of the same character as the influence which the motions of respiration exert. They may be properly overlooked in a general statement of the causes of the circulation.

From the lungs, in what direction does the blood flow? What is to be remarked as respects the direction of the circulation in the system and in the lungs? What is the conclusion as respects the heart's action?

By regarding the affinity between the blood and the tissues with which it is in contact as the great primary cause of the circulation, we assign a reason for those various phenomena which can not be accounted for on Harvey's doctrine: the motions in the embryo; the periodic and local variations; the portal circulation; the changes in the current, as seen under the microscope; the movement in the capillaries after the heart is cut out; the empty condition of the arteries after death; the phenomena of acardiac fœtuses; local inflammations and congestions; the gangrene of parts while their capillaries are pervious; the retardation of the current on the application of cold or of carbonic acid gas; the results of asphyxia and death by drowning or hanging; the changes of pressure in the arteries and veins respectively during a check on the respiration; the vis a tergo of the veins; the effects of a ligature on those vessels; the action of irrespirable gases when breathed, and the opposite conditions when oxygen gas or protoxide of nitrogen are used.

Among the striking proofs of the truth of this doctrine, that the primary cause of the circulation is the aeration of the blood, I would particularly direct attention to the effects which ensue in the moment of birth at the first breath. That intercommunication between the two sides of the heart, established through the foramen ovale and through the ductus arteriosus, is suddenly put an end to. But this is not through any change in the mechanism of the heart itself, nor because of any interruption in the action of the placenta. It is solely because of the calling into operation of the principle I have been here enforcing. Through the contact of the cold air, or other causes, the inspiratory muscles make their first contraction and distend the lungs. At that instant, the commencing arterialization produces a pressure, in the manner I have explained, of the venous upon the now arterialized blood in the vessels of the pulmonary cells. There is no other possible issue to such an action than an instant drain upon the heart. The pulmonary or less circulation sets in with full vigor. The

Mention some of the facts that this doctrine will explain. Describe particularly the change in the circulation at the first breath. How is that change to be explained?

blood is not driven by the heart to the lungs, but drained by the lungs from the heart. If it were the heart's action that occasioned this sudden increase of force, because of the strain thrown upon it through the shutting off of the influence of the placenta, it is inconceivable why the current should not continue to move through the great avenues already open to it from the right to the left auricle through the foramen ovale, and from the right ventricle into the aorta through the ductus arteriosus. The arrest of its motion through these channels distinctly establishes that the seat of the new action is in the lungs, and the final closure of the foramen and shriveling of the duct confirm the correctness of this conclusion.

A doctrine which accounts with simplicity for such a long list of miscellaneous facts commends itself to our attention at once. There are, however, considerations of a still weightier character, compelling us to adopt it. The affinity between the blood and the parts it is brought in contact with is a chemical fact beyond contradiction. The pressures and motions I have been speaking of follow as the inevitable consequences of that affinity. We can not, therefore, gainsay their existence in the living mechanism, and the only doubt we can entertain is as to whether they are of competent power to produce all the effects before us. But after what has been already said respecting the energy of endosmotic movements displayed against pressures of many atmospheres, we may abandon those doubts; and since we have here a force of universality enough, and intensity enough, and in every instance acting in the right direction, it would be unphilosophical to look farther, since such a force *must*, under these conditions, exist in the physical necessity of the case.

Is the energy of the force in the capillaries sufficient to account for the circulation?

CHAPTER IX.

OF RESPIRATION.

Respiration introduces and removes aerial Substances. —Physical and Chemical Conditions of Respiration. —Interstitial Movements of Gases.—Condition of Equilibrium in the Diffusion of Gases.—Condensing Action of Membranes.—Forms of Respiratory Mechanism.—The Lungs of Man.—Three Stages in the Introduction of Air: Atmospheric Pressure, Diffusion of Gases, and Condensation by Membranes.—Variations in the expired Air.—Effect of irrespirable Gases.—Nervous Influence concerned in Respiration. —Results of Respiration.

Since it is essentially necessary to the life of all animals that the blood should pass to every part of the system, provision must be made for securing aeration. The breathing apparatus is the skin, or some extension, reflection, or modification of it.

Besides the great duty of originating the circulation, respiration is connected with others of equal importance. The functional activity of the nervous and muscular tissues is dependent on their oxidation, and this implies the introduction of air. In each animal tribe, moreover, it is necessary to keep the temperature up to a specific point. This also is accomplished by oxidation, either of the disintegrating material passing to waste, or of combustible substances, such as sugar or fat.

All organic material, at its death, eventually gives origin, under the action of the air, to two products with which the function of respiration is mainly concerned. These products are carbonic acid and water. With the exception of gelatin, the other respiratory elements of food—fat, sugar, starch, etc., yield these two products alone. The nutritive elements give rise to nitrogenized

What is the object of the breathing apparatus? On what does the action of the nerves and muscles depend? With what products of decay is respiration concerned? What products do the respiratory and nutritive food elements give rise to?

compounds in addition. The conditions of life are such that carbonic acid can not be permitted to accumulate in the system, and means have therefore to be resorted to for its removal. The introduction of oxygen and excretion of carbonic acid are accomplished by the same mechanism, the lungs.

Under its simplest condition, respiration consists in the passing of carbonic acid with the vapor of water from the system, and the reception of oxygen in exchange. The construction of the apparatus accomplishing this double duty in atmospheric animals is such that it can deal with substances in the aerial state alone. Nothing can be introduced through the lungs or escape therefrom except it be in the gaseous or vaporous form. All those products of disorganization not presented under this condition must therefore be removed by other organs, and this is more particularly done by the kidneys.

Respiration, like circulation, furnishes us with a signal instance of the employment of purely physical principles for the accomplishment of physiological purposes. It is with the pressure of the atmosphere, the diffusion of gases, and the condensing action of membranes that we have now to deal. These give us so precise and perspicuous an explanation of the act of breathing that it is needless to look beyond them; yet on that act depend the highest operations of life.

Of the physical principles now to be dealt with, it is unnecessary to say any thing respecting the pressure of the atmosphere, since that is well understood; but not so with the phenomena of the diffusion of gases, and the condensing action of membranes.

If a light gas be placed above a heavy gas in a suitable apparatus, the former, notwithstanding its levity, will descend, and the latter, notwithstanding its weight, will rise, and a complete and uniform intermixture will result.

Thus, if a vial filled with hydrogen be placed with its mouth downward over the mouth of a vial of the same size containing carbonic acid gas, as shown at *h*, *c*, *Fig.* 54 (page 136), in the course of a few moments the diffusion will be complete, and if the mixture in either vial

With what class of substances is respiration connected? How may the free diffusion of gases be illustrated?

Fig. 54.



Diffusion of gases.

be examined, it will be found to contain equal quantities of the gases.

Perhaps the most satisfactory method of illustrating the passage of gases through barriers is by taking a porous earthenware cylinder, *a a*, *Fig.* 55, drying it perfectly, and cementing into its mouth an open glass tube, *b*, three quarters of an inch in diameter, and a foot or more long. A wide-mouthed bottle, *c c*, being placed as a temporary cover over the porous cylinder, it may be filled with hydrogen gas by displacement; and if the end of the glass tube be put into water contained in a reservoir, *d*, the water will rush up the moment the bottle is removed. When this motion is completed, if a jar of hydrogen be held over the cylinder, the water will be driven down with great rapidity, and a number of air-bubbles quickly escape. The extraordinary speed with which a gas will flow in and out of pores could not be better displayed. This rapidity of motion is an element with which the physiologist has to deal, as we shall presently find.

Fig. 55.



Diffusion through earthenware.

Even when the texture of the substance is much closer, and the pores of extreme minuteness, similar results can be obtained, as was shown in the experiments of Dr. Mitchell, of Philadelphia, who employed thin sheets of India-rubber. If, over the mouth of a glass bottle, such a thin tissue be tightly tied, and the bottle placed in an atmosphere of carbonic acid gas, movement at once takes place, a little air flowing out of the bottle into the carbonic acid, and so large a quantity of the acid passing the opposite way that the India-rubber soon swells outward, and eventually caps the bottle like a dome, as in *Fig.* 56, at *b*. Or, if the conditions be reversed, the bot-

How may it be shown that they can pass through porous barriers? Describe Dr. Mitchell's experiment.

tle being filled with carbonic acid, and then exposed to the atmosphere, the India-rubber will be depressed, as at *a*, and stretch so as almost to sink to the bottom. Such experiments therefore prove that, even though barriers of a very close texture should intervene, gases will pass through them, and with so much force, as Dr. Mitchell showed, that many inches of mercury might be lifted; nor does the movement cease until the gases on both sides of the membrane have the same composition.

Fig. 56.



Diffusion through India-rubber.

Other substances having a close texture may be thus readily permeated. I found that a little bladder of shellac, blown on the end of a glass tube, permitted the passage of the vapor arising from water of ammonia. The instantaneousness of these motions is, however, most beautifully illustrated by employing soap-bubbles, the liquid nature of which excludes the idea of pores in the strict acceptation of that term. If a bottle, *a a*, *Fig.* 57, be rinsed out with ammonia, and then, by means of a piece of glass tube, *b b*, a soap-bubble, *c*, be blown therein, the air from the bubble being immediately drawn into the mouth without a moment's delay, the strong taste of the ammonia is perceived. Or if a rod, dipped in hydrochloric acid, be presented to the projecting end of the glass tube, copious white fumes arise. This therefore shows that vapors will pass through barriers having no proper pores, the transit taking place instantaneously.

Fig. 57.



Instantaneous passage of gases through films.

Against what amount of force can such diffusions take place? Describe the illustration, *Fig.* 57. How may it be proved that ammonia instantly passes through the soap-bubble?

Soap films enable us to demonstrate the endosmosis of gases in a very advantageous manner, owing to their cohesiveness and thinness. If the finger be dipped in soap-water, and then rapidly passed over the mouth of an empty bottle, so as to leave a horizontal film attached across, on exposing the bottle to carbonic acid gas, the horizontality of the film is immediately disturbed, and it soon swells up into an almost spherical dome. Or if the bottle be filled with carbonic acid, and then exposed to the air, the film is promptly depressed into a deep concavity, and bursts. By these methods the passage of all kinds of vapors and gases may be demonstrated, oxygen, hydrogen, carbonic acid, protoxide of nitrogen, the vapors of peppermint, lavender, and various essential oils.

By many experiments on such different substances, I found that the law of equilibrium for gases and vapors is the same as for liquids. No matter what the thickness or thinness of a porous barrier may be, movement takes place through it, until the media on its opposite sides have the same chemical composition. The observed action, in particular cases, will therefore altogether depend on the circumstances under which the experiment is made. A soap-bubble full of carbonic acid, exposed to the air in a closed bottle, collapses only to a certain extent when the percentage constitution of the air it contains is the same as that of the air in the bottle, contaminated with the carbonic acid the bubble has yielded it. But if the bubble be exposed to the free atmosphere, it collapses almost completely, for now the carbonic acid escapes finally away.

One of the most interesting facts connected with these results is the perfect manner in which a film of excessive tenuity will discharge these mechanical functions. With a little care, a film may be obtained so thin as to be invisible except in certain lights, when it presents a velvety black aspect. In this condition, as Newton has proved, it is not thicker than three eighths of a millionth of an inch, yet endosmosis takes place perfectly through it: it expands and collapses, rises up into a dome, or is

What is the law of equilibrium in these cases? Why does a soap-bubble containing carbonic acid collapse almost completely in air? How do films of extreme thinness act?

depressed into a concavity, as the circumstances of its exposure may be. And this should prepare us to admit that in organic tissues of the utmost degree of tenuity these physical phenomena may occur, and that even under these most unlikely circumstances such tissues may give origin to mechanical forces of the greatest intensity, as we shall now prove.

The law of the diffusion of gases has but a very limited physiological application. The introduction of it in cases to which it does not properly apply has led to several errors. There is nothing common in the result of the movement of gases exposed freely to one another, and exposed with the intervention of a close-pored tissue. The tissue itself gives origin to mechanical force of such intensity as not only to modify the diffusion rate, but, in a great many of the most important cases, absolutely to invert the direction of the motion. Thus, through a mass of stucco, in which the pores are of sensible size, atmospheric air passes more rapidly to carbonic acid than carbonic acid does to it, but through the thinnest film of water the reverse takes place. A bubble full of that acid, exposed to the air, lets it escape with so much rapidity that in a few moments a complete collapse has occurred. If the law of diffusion here held good, the bubble should rapidly distend.

Moist membranes and films of water, by reason of their chemical affinity for gaseous substances, and their consequent condensing action, become the origin of great mechanical power. Under such conditions, I have shown that carbonic acid passes into atmospheric air, driven, as it were, by the action of the membrane against a pressure of ten atmospheres, and sulphureted hydrogen against a pressure of twenty-five atmospheres, and, even against these great resistances, the passage is accomplished with so much promptness as to lead to the inference that a membrane will cause one gas to diffuse into another, even though the apparent resistance be indefinitely great.

In *Fig.* 58 (page 140) is given a representation of the arrangement by which these results were obtained. It consists of a strong glass tube, seven inches or more in

Does the law of diffusion apply in these cases? Against what amount of resistance has the diffusion of gases been witnessed?

Fig. 58.



Great force of infiltration.

length and half an inch in diameter, hermetically closed at one end, through which a pair of platinum wires, *b*, *c*, pass into the interior of the tube parallel, but not touching. The other end, *a a*, has a lip or rim turned on it. Between the platinum wires, a gauge-tube, *d*, is dropped, to show the amount of condensation. On the top of the gauge-tube a small test-tube, *f*, is placed, to contain a reagent suited to the gas under trial, as lime-water for carbonic acid, acetate of lead for sulphureted hydrogen, litmus water for sulphurous acid. Sometimes, instead of this test-tube, a piece of paper, soaked in the proper reagent, was employed. The large tube was then filled with water to the height *e e*. Its lip or rim, *a a*, being next smeared with burnt India-rubber, to insure absolute freedom from leakage, a thin sheet of India-rubber was tied tightly over it, and over this again, to give strength, a very stout piece of silk. Every thing being thus arranged, the projecting wires, *b*, *c*, were connected with a voltaic pile, decomposition of the water ensued, oxygen and hydrogen being disengaged, and a condensed mixture of atmospheric air and those gases accumulated in the space *a a e e*, the gauge-tube showing the extent to which the condensation had gone. Now if the little tube, *f*, had been filled previously with lime-water, and the whole arrangement was introduced into a jar of carbonic acid gas, the upper part of the lime-water presently became milky, and after a time a copious precipitate of carbonate of lime subsided. This would readily take place when the gauge was indicating a pressure of ten atmospheres. In like manner, when a piece of paper imbued with carbonate of lead had been introduced into the tube, and a pressure of 24¼ atmospheres accumulated, on introducing the instrument into a vessel of sulphureted hydrogen, the paper quickly became brown. Sulphureted hydrogen can therefore pass through a sheet of India-rubber and diffuse into an atmosphere of oxygen, hydrogen, and at-

Describe the experiment illustrated in *Fig.* 58. How in that instrument is the force of infiltration measured?

mospheric air beyond, though it is resisted by a pressure equal to that of 800 feet of water.

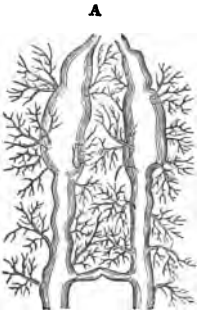
The method of condensation here employed, because of its freedom from mechanical concussions, enabled me to continue these researches up to pressures of 50 atmospheres without leakage, in comparatively slender tubes, and even under these circumstances gaseous diffusion seemed to take place without any restraint.

It would lead me too far from my present object to pursue the consideration of these facts, and I must therefore be content to refer the reader to the memoirs in which they have been specially discussed.*

Under its simplest aspect, the act of breathing consists in the elimination of carbonic acid from the system, and the introduction of oxygen. The manner in which the respiratory surface frees itself from the former, and secures new supplies of the latter, differs very greatly. In the lower aquatic animals currents are established in the water by the aid of ciliary motion, and by these the necessary changes are made. In others, in which respiration is conducted by the skin, incessant locomotion is relied on, and again, in others, the water is drawn into the stomach and intestinal canal, and every part bathed with the aerating medium.

In insects, the type of carrying air to the blood is developed to the utmost degree, there being great numbers of tracheal tubes pervading all the soft parts. These occasionally present dilatations, acting as reservoirs — the foreshadowing of the respiratory cavities of the higher tribes. Of such, *Fig.* 59, representing the air-sacs or tracheal dilatations of the scolia hortorum, is an illustration. The tracheal tubes communicate with the external air

Fig. 59.



Air-sacs of insects.

* American Journal of Medical Sciences, May, 1838.

To what pressures may these examinations be continued? What is the immediate purpose of the act of respiration? How is this accomplished in the lower aquatic animals? What is the type of respiration in insects? Describe the illustrations in *Figs.* 59, 60.

through openings which may be obstructed by a valvular arrangement, as represented in *Fig.* 60. The pho-

Fig. 60.

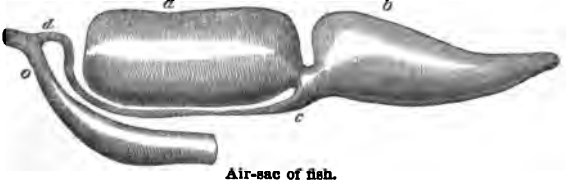


Spiracle of insect.

tograph from which this figure was taken shows such a spiracle magnified 75 diameters. These organs may be seen arranged in rows on each side of the body, as in the common caterpillar. The mode of guarding the orifice varies in different cases, sometimes tufts of hair being resorted to, and sometimes, as in the figure, valves.

The true lung is first recognized in the swimming bladder of fishes as a simple sac. In the carp, the tendency to a multi-chambered construction already appears under the form of two such bladders, *a*, *b*, com-

Fig. 61.



Air-sac of fish.

municating with each other through a narrow tube. These are connected with the œsophagus, *o*, by means of the pipe *c*, *d*, the fish being thus enabled to remove

Under what circumstances does the true lung first appear?

at pleasure a part of the air contained in the sacs by muscular compression. Though this mechanism is a rudimentary lung, it does not properly subserve the duty of such an organ, but is employed for producing variations in the specific gravity of the animal by introduction or removal of air. In these tribes the gills are the mechanism for aeration. It is accomplished in the following manner: The mouth is periodically filled with water, which is driven past the gills by muscular compression, and thereby the carbonic acid is removed from the blood circulating in those organs, and oxygen is obtained in return. For this reason, a fish dies very quickly when its mouth is kept open. The angler knows that it is not owing to any loss of blood, nor to any injurious lesion that the hook may cause, but simply to suffocation, the water no longer lifting the gill covers, but merely passing out through the open mouth.

The experiments of Humboldt and Provençal clearly demonstrate the analogy between aquatic and aerial respirations; for water is not decomposed by the breathing of fishes: it is the air dissolved in it that is used. In the sample examined by these chemists, there was 20.3 per cent. of its volume of air, consisting of oxygen 29.8, nitrogen 66.2, and carbonic acid 4.0, in the hundred parts. After the fishes had remained in it for a due time, it still contained 17.6 per cent. of its volume of air, but this in 100 parts now consisted of oxygen 2.3, nitrogen 63.9, and carbonic acid 33.8. There had therefore been a consumption of oxygen and evolution of carbonic acid, together with a slight removal of nitrogen, this being the general result witnessed in aerial respiration. In a similar course of experiments on the breathing of gold fishes, made by myself, the result corresponds to the preceding statement, only the water I used was richer in oxygen gas, and the transposition into carbonic acid did not seem by any means to be so complete. I also remarked the same diminution in the quantity of nitrogen, but am disposed to attribute it not so much to the consumption of that gas by the fishes as to its diffusion from

What function does the swimming bladder of fishes discharge? How is the respiration of fishes carried on? Why is it that a fish dies so quickly on the hook? What is the constitution of the air contained in water?

Fig. 62.

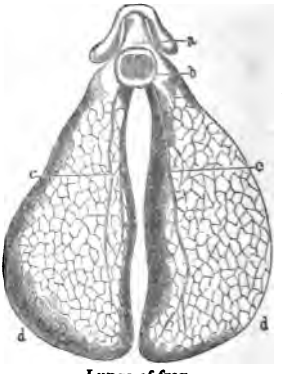


Lung of reptile.

the water into the atmosphere, the solvent power having changed by the substitution of carbonic acid for oxygen.

In reptiles the lung presents the sac-like form, as in *Fig.* 62, a pulmonary artery passing on one side, and a pulmonary vein returning on the other: *a* is the trachea; *b*, its bifurcation; *c*, pulmonary artery; *d d*, pulmonary vein. It often occurs that the two lungs are not equally developed, one of them, B, being rudimentary as compared with the other, A. Into such a sac in serpents the air is forced by muscular contraction, a kind of swallowing. It is expelled from them by the contraction of the abdominal muscles, and hence the hissing sound emitted during its expulsion. From the simple sac to the cellular lung the advance is made by degrees, a development of parietal cells upon the inner surface taking place. At the intermediate stage between the simple sac and the highly subdivided respiratory organ of the mammals, the condition of things is well illustrated by the lungs of the frog. In *Fig.* 63, *a* is the hyoid apparatus; *b*, cartilaginous ring at the root of the lungs; *c*, the pulmonary vessels; and *d d*, the pulmonary sacs.

Fig. 63.



Lungs of frog.

Of all tribes, the respiratory mechanism is most highly developed in birds, which, besides being provided with lungs, have air-sacs between the muscles, and respiratory membranes spread on the interior of the hollow bones. It

What change does the breathing of fishes impress on it? How is the respiration of reptiles carried on? Describe *Fig.* 63.

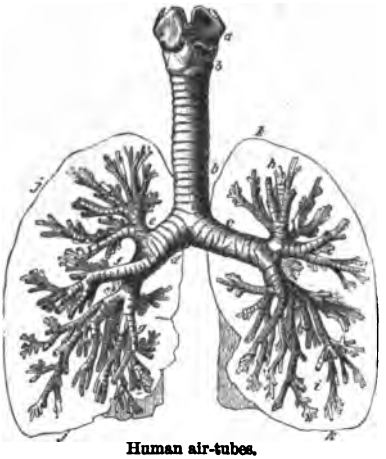
is in consequence of this that a bird is killed so readily, even by a very small shot, since it is scarcely possible to make a perforation into any part of the body without opening the respiratory cavity.

In man, the bronchial tube, as it passes into each lung, branches forth like a tree, the walls of the tubelets thus arising having cartilaginous rings to preserve their form under compression, circular organic muscular fibres to enable them to contract, and longitudinal fasces of elastic tissue to shorten them after extension. In their interior they are covered with mucous membrane provided with cilia. When the proper degree of minuteness, about $\frac{1}{60}$ of an inch, is reached, they consist alone of elastic membrane, interspersed with muscular fibres, and upon their sides the air-cells open; sometimes single ones, or sometimes many cells communicating with one another, discharge through the same orifice, the tubelet itself ending in a cell. The air-cells have various dimensions, from $\frac{1}{70}$ to $\frac{1}{1200}$ of an inch. Their structure is like that of the tubelet. The pulmonary capillaries are spread so closely upon them that the spaces between them are less than their own diameter, which, on an average, is $\frac{1}{3000}$ of an inch. As the cells are close together, the blood-vessels passing between them are brought in communication with the air on both sides, and arterialization is thus rapidly and completely performed. Each tubelet, with the air-cells thus clustered upon it, is a miniature representation of the lung of a reptile. The cells themselves communicate by lateral apertures with one another. The membrane lining their interior is sharply folded at the apertures, and there are reasons for supposing that it contains organic muscular fibres. It is stated that each terminal bronchus has nearly 20,000 air-cells clustered upon it, and that the total number is 600 millions.

The mode of distribution of the air-tubes is represented in *Fig.* 64 (page 146). *a* is the larynx; *b b*, the trachea, the upper letter corresponding to the cricoid cartilage; *c*, the left bronchus; *d*, the right bronchus; *e*, *f*, *g*, its ram-

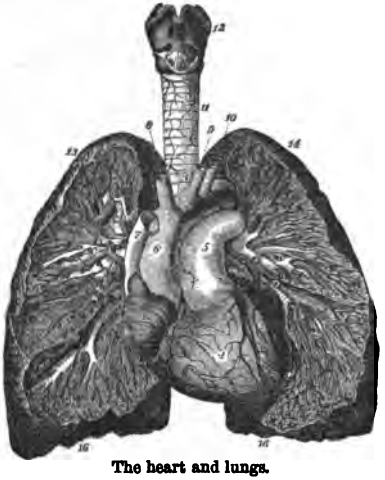
What is the reason birds are so easily killed by a small shot? Describe the human lung. What is the size of the air-cells? How are the blood-vessels arranged between them? What is the estimated number of air-cells?

Fig. 64.



Human air-tubes.

Fig. 65.



The heart and lungs.

ifications in the right lung, *j j*; *h*, *i*, ramifications of the left bronchus in the left lung, *k k*.

Fig. 65, arrangement of the heart and lungs, the latter in part section. 1, left auricle of the heart; 2, right auricle; 3, left ventricle; 4, right ventricle; 5, pulmonary artery; 6, aorta; 7, superior vena cava; 8, innominata; 9, left primitive carotid; 10, left subclavian; 11, 12, upper rings of trachea and cartilages of the larynx; 13, upper lobe of right lung; 14, upper lobe of left lung; 15, the right pulmonary artery; 16, 16, lower lobes of lungs.

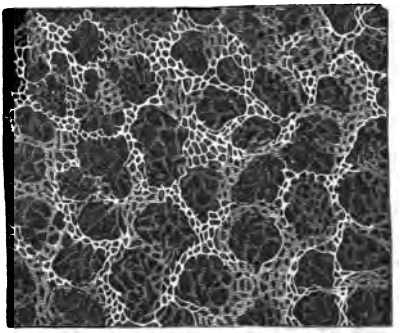
Fig. 66 illustrates the manner of distribution of blood-vessels on the air-cells of the lungs.

By the aid of this elaborately constructed mechanism the air is brought to the blood. There are three distinct stages through which it has to pass. The first is the filling of the tra-

Describe *Figs.* 64 and 65. How many stages are there in the introduction of the air?

chea and larger ramifications of the bronchial tubes: this is accomplished by atmospheric pressure, brought into play by muscular contraction. The second stage is the translation of the fresh air from the larger bronchial tubes to the ultimate air-cells: this is accomplished on the principle of gaseous diffusion. The third stage is the passage from the air-cells into the blood: this is through the wall of the cell, the wall of the blood-vessel, and the sac of the blood-disc; it involves passage through membranes, and implies their condensing action. Each of these three stages we have now to consider.

Fig. 66.



Distribution of capillaries on air-cells of the lungs.

1st. The introduction of fresh air into the trachea and larger ramifications of the bronchial tubes is accomplished by muscular contraction, calling into operation atmospheric pressure. In tranquil respiration the diaphragm is nearly sufficient for this purpose. This muscle, forming the convex floor of the chest, as soon as it contracts, assumes more nearly a plane figure, thereby increasing the content of that cavity; and, just as in a common bellows, when the lower board is depressed, the air flows in through the pipe, so, on the descent of the diaphragm, the air flows in through the trachea, forced by the external pressure.

An experimental illustration of the manner in which the air is introduced into the cavity of the lungs by the descent of the floor of the chest, and then expelled by its elevation, is represented in *Fig.* 67 (p. 148). *a a* is a tube of glass half an inch or more in diameter, and six or eight inches long; to the lower end of it a bladder, *b*, is tightly attached. The tube is passed through the neck of a

Describe the first stage. What is the mode of action of the diaphragm?

Fig. 67.



Mechanism of Respiration.

bell-jar, *c c*, air tight. A large glass reservoir of water, filled to the height *d d*, receives the bell-jar, as shown in the figure. When the jar is depressed in the water the air is expelled from the bladder, and when the jar is raised the air flows in. By alternately elevating and depressing the bell, the bladder executes movements like those of the lungs, of which, indeed, it is a representation; the glass tube being the trachea, the bell-jar the walls of the chest, and the rising and falling water-level the rising and falling diaphragm. In this illustration the bladder is, of course, perfectly passive, as was at one time supposed to be the case with the lungs: an erroneous opinion, presently to be corrected.

In the mature period of life, and especially in deep respiration, the action of the diaphragm is insufficient for the introduction of air, and a still farther volume is obtained by raising the ribs, which increases the dimensions of the chest from right to left, and also from front to back. In men, this effect takes place more particularly through the movements of the lower ribs, and this form of respiration is therefore sometimes called the inferior-costal; but in women the upper ribs are more movable, the dilatation of the chest is there greater, and the respiration therefore designated as the superior-costal. In these movements of the ribs, and especially in violent respiration, many muscles are involved.

In the reverse act, that is, in expiration, or the expulsion of air through the trachea, the floor of the chest is raised. The diaphragm, when it contracted, made press-

What does *Fig.* 67 illustrate? In deep respiration, what more is done? What difference is there between the respiration of men and women? How is the expulsion of the air accomplished?

ure upon the viscera of the abdomen, and forced the muscular walls of that cavity outward; but, as soon as the diaphragm relaxes, the abdominal muscles contract, and thus an antagonizing force is originated tending to expel the air. In this the elasticity of the lungs and of the walls of the thorax itself affords a great assistance. Owing to this elasticity, the muscular exertion required for the introduction of the air greatly exceeds that required for its expulsion.

In tranquil respiration, we may regard the changing of the air to be accomplished by the alternate depression and elevation of the diaphragmatic floor of the chest. On an average, this takes place 17 times in a minute, and in an adult of the standard size we may assume that 17 cubic inches of air are introduced at each inspiration. One breath in five is usually deeper than the other four. The statement often made, that five pulsations correspond to one respiration, must be received with a certain restriction. In pneumonia, the respirations may be to the pulsations as 1 to 2; in typhoid fever, as 1 to 8; and even in a state of health there may be considerable variations.

By muscular movements, thus calling into action atmospheric pressure, the air is drawn, but not forced, into the respiratory apparatus. Considering, however, the contents of the lungs, which can not be taken at less than 200 cubic inches, it is clear that the amount is not more than sufficient to fill the nasal passages, the trachea, and the larger ramifications of the bronchial tubes. Lying nearest to the outlet, it would be the first to be expelled by the act of expiration. There could be no exchange of the fresh for the foul air unless some additional means were employed for accomplishing its transference from the larger ramifications of the bronchial tubes to the remotest air-cells.

2d. The transference of fresh air to the cells is accomplished by resorting to two different principles, the diffusion of free gases into one another, and muscular contraction.

An estimate of the relative share taken by each of

How does the elasticity of the lungs operate? What is the number of respirations in a minute? How many cubic inches of air are received?

these is arrived at by an examination of the absolute velocity with which gases diffuse into one another. The statement that gases act as vacua to each other has led to some very erroneous conclusions. It has been taken for granted that the actual diffusion is very rapid, perhaps approaching to the velocity of gases rushing into a void. But I have shown* that this is altogether a misconception, and that the transit of fresh air from the bronchi, exchanging with foul air from the cells, if conducted on that principle alone, would require a period greatly beyond the time occupied for one respiratory act, about three seconds and a half.

To an additional agent we must therefore look for a complete explanation, and this, I think, is presented in the circular organic fibres of the bronchial tubes and cells. It has long been understood that these possess the power of varying the capacity of the tubes.

With this agency in view, this second stage of the process is accomplished as follows: The carbonic acid, vapor of water, and excess of nitrogen, if any, that have accumulated in the cells belonging to any given bronchial tree, are expelled therefrom by the muscular contraction of the circular organic fibres, and are delivered into the larger bronchial tubes, in which diffusion at once takes place with the air just introduced. As soon as the expiration is completed, relaxation of the muscular fibres occurs, and the passages and cells dilating, both through their own elasticity and the exhaustive effect arising from the simultaneous contraction of other bronchial trees, fresh air is drawn into them, the alternate expulsion and introduction being accomplished by muscular contraction and elasticity, the different bronchial trees coming into action at different periods of time, some being contracting while others are dilating.

3d. The third stage is the passage of oxygen from the cells to the blood: it is through the wall of the cell, the wall of the blood-vessel, and the sac of the blood-disc. The carbonic acid issues from the plasma, and passes

* American Journal of Med. Sciences, April, 1852.

At what rate does respiratory diffusion take place? What is the action of the muscle fibres of the lungs? Explain the third stage of respiration.

through the wall of the blood-vessel and the wall of the cell.

Many physiologists have supposed that this exchange of oxygen for carbonic acid takes place on the principle of diffusion. On the authority of Valentin and Brunner, it has been asserted that the proportional exchange actually observed is 1174 of oxygen for 1000 of carbonic acid, these being the theoretical quantities under the law of diffusion; but there is no difficulty in proving that this is a physical impossibility, for the exchange is not merely that of oxygen and carbonic acid; it is much more complicated. The lungs regulate the quantity of free nitrogen in the system, and there is a constant escape of the vapor of water. These bodies, moreover, are not presented in the gaseous state, but in that of liquid solution, and the wall of the cell, of the pulmonary capillary, and of the blood-disc, by their condensing action, totally disturb the conditions of diffusion.

EXPLANATION OF RESPIRATION.

The act of respiration in man is therefore accomplished in the following way. The air, introduced by atmospheric pressure, brought into play by the action of the diaphragm and other respiratory muscles, fills the nasal passages, the trachea, and larger ramifications of the bronchial tubes. Between it and the gas coming from the pulmonary vesicles, diffusion steadily takes place, tending to remove the cell gas into the atmosphere; but this gas is not brought from the vesicles by diffusion alone, which could not act with sufficient speed, but by the contraction of the circular organic muscles of the bronchial tubelets and of the cells, the different bronchial trees not acting simultaneously, but successively. As soon as contraction is over, the tubes expand by their elasticity, and the air is drawn into the cells, each bronchial tree, by its contraction, aiding the expansion of the adjacent ones. The lungs are therefore not altogether passive during respiration, as is sometimes said. The exchange between the gas in the cells and that in the blood does not take place through simple diffusion, or in quantities proportional to the diffusion

Does the principle of simple diffusion here apply? Give a general explanation of the respiratory process.

volumes of oxygen and carbonic acid. It is a complex diffusion, disturbances arising from the gases in the blood being either dissolved or combined. The process ends by the expulsion of the foul air accumulated in the larger bronchi and trachea, by the diminution which takes place in the capacity of the chest during expiration, occasioned by the contraction of the expiratory muscles, the elasticity of the walls of the chest, and of the lungs themselves.

Such is the arrangement by which fresh air is constantly presented to the blood, and the gases and vapors exhaling from it are removed. The degree of exhaustion occurring in the chest scarcely justifies the expression sometimes used, "a tendency to a vacuum," since it is rarely more than competent to raise water a single inch. This may be readily proved by dipping a glass tube, open at both ends, and half an inch in diameter, into a cup of water, and placing the projecting extremity between the lips, taking care to keep the muscles of the mouth at complete rest. It will then be seen that at each inspiration the water rises about an inch, and at each expiration is depressed to a similar extent. Its movements indicate the degree of rarefaction or compression occurring in the chest.

The diurnal amount of air introduced into the lungs has been variously estimated from 226 to 399 cubic feet. A part, from 4 to 6 per cent., of the oxygen thus introduced disappears in the lungs, and the expired air is charged with from 3 to 5 per cent. of carbonic acid. But that nothing analogous to combustion occurs in those organs is proved by their temperature, which is not higher than that of other parts of the system. Moreover, carbonic acid can be withdrawn from venous blood in a Toricellian vacuum, and still better by agitating the blood with such gases as hydrogen and nitrogen, proving that the gas pre-exists in the venous blood before its entry into the lungs, and is not formed in those organs, unless, indeed, it exists as a bicarbonate, as already mentioned. The quantity of carbonic acid thus disen-

What is the actual amount of rarefaction in the lungs? How may it be measured? What is the diurnal amount of air introduced? How is it known that nothing like combustion occurs in respiration?

gaged is less than the quantity of oxygen absorbed, because much of the latter is consumed in the production of sulphuric and phosphoric acids, which escape in the urinary secretion, as indeed does a large quantity of carbonic acid itself.

With respect to the ratio between the quantity of oxygen inspired and that contained in the expired carbonic acid, a variation will be observed, depending on many conditions, as, for example, on the nature of the food.

For the perfect oxidation of the different elements of food, very different quantities of oxygen are required; thus, for the oxidation of 100 parts of fat, it would require 292.14 of oxygen; for that of starch, 118.52; for that of muscle, 147.04.

For reasons to be considered when we treat of the production of heat, the quantity of carbonic acid disengaged varies with external circumstances. When the weather is cold it is greater than when it is warm. Thus at 68° there is twice as much liberated as at 106°. It increases during exercise and after eating, but diminishes during sleep. More is set free by men than by women; it also varies with age, the proportion rising from eight years to thirty, remaining stationary to forty, and then declining. It changes with the frequency of the respirations. The total quantity of carbon daily removed by respiration may be estimated at eight ounces.

Besides the carbonic acid removed, a large quantity of water is excreted by the lungs, for the expired air may be regarded as saturated, or containing the maximum quantity of water for 94°. For the vaporization of this water much heat is consumed, as is likewise the case for the warming of the introduced air, which, no matter what the external temperature may have been, is brought to that of the lungs.

With respect to the absolute amount of air expired, and also the quantity of water removed by the lungs, some experiments have been made by my son, Dr. J. C.

Why is the quantity of carbonic acid less than that of oxygen in volume? What amount of oxygen is required in the case of fat, starch, and muscle, if used as food? What circumstances control the amount of oxygen disengaged? How much carbon is daily removed?

Draper; the principle upon which they were conducted may be thus briefly stated. The air from the lungs, which has a dew-point of 94°, was passed by a wide tube through a metallic condenser kept at 32°, care being taken to have as little obstruction as possible to its egress. The weight of the water collected in the condenser furnished the means of calculating, by a simple formula, the quantity of air expired, for the vapor, leaving the respiratory passages at 94°, and that leaving the condenser at 32°, were at their maximum densities. Computations executed upon data obtained on this principle furnish the following, among other interesting results:

1. On making sixteen respirations in the minute, and continuing the experiment for twenty minutes, the average of five different series of experiments gives 622 cubic inches of air expired each minute.

2. On making six respirations in a minute, and continuing the trial for twenty minutes, the average of three series of experiments gives 511 cubic inches for the air expired each minute.

3. On making thirty-three respirations in a minute, and continuing the experiment for twenty minutes, the average amount of air is 1077 cubic inches for the air expired in each minute.

On comparing these three statements, it appears that, the first representing normal, the second very slow, the third very quick respiration, the absolute amount of air removed from the lungs is directly proportional to the number of respiratory acts in a given period of time, and this notwithstanding such variations in the depth of the inspirations as under such circumstances are likely to occur.

With respect to the quantity of water removed from the lungs, he also shows,

4. That, at an atmospheric temperature of 55°, the dew-point being 49°, the number of expirations sixteen per minute, the quantity of water removed per minute is 4.416 grains.

Give an account of the experimental results related in sections 1, 2, 3. What is the effect in normal, slow, and quick respiration? What is the quantity of water exhaled per minute, as shown in section 4?

5. The other conditions remaining the same, but the respirations reduced to six per minute, the amount of water removed per minute is 3.586 grains.

6. The other conditions remaining as before, but the number of respirations increased to thirty-three per minute, the amount of water removed per minute is 7.560 grains.

From these statements it therefore appears that the quantity of water removed from the blood by respiration increases with the frequency of the respiratory acts, and this notwithstanding variations which, under such circumstances, must take place in their depth. Theoretically, it is also obvious that the absolute amount thus expired is dependent on the existing dew-point of the air.

The time of exposure of the blood to the air is only a second or two. The color changes, as has been described before, from blue to crimson, and the temperature rises a degree or two, as is shown by an examination of the left cavities of the heart. The water thus removed is not pure, but contains animal matter in a state of decay.

Though we have treated of the act of respiration as consisting of two separate and consecutive stages, inspiration and expiration, in reality it proceeds continuously. At the respiratory surface, which is the wall of the air-cell, the passage of oxygen inward, and of carbonic acid and steam outward, takes place in a steady and unvarying manner.

The introduction of an irrespirable gas into the lungs, or the prevention of the access of the atmosphere, brings the circulation of the blood to a stop; for that movement depends, as I have shown, on the aeration taking place in the pulmonary capillaries. In such cases there will be an engorgement of the right heart and vessels arising therefrom, but, if the stoppage has not lasted too long, the current may be re-established by re-establishing the respiration. Death commonly ensues on an exclusion of the air for five minutes, and, in cases of drown-

What is the quantity of water exhaled per minute, as shown in sections 5 and 6, and how does it vary? For what length of time is the blood exposed to the air? Is respiration continuous or reciprocating? What is the effect of the introduction of irrespirable gases?

ing, it is rare for restoration to be effected if the immersion has lasted more than four.

In the respiration of protoxide of nitrogen, a gas which is an energetic supporter of combustion, and acting more powerfully on the animal system when respired than even oxygen itself, on account of its ready condensibility by pressure, or by membranes, and solubility in water, the circulation is greatly quickened at first, and a state of exhilaration ensues; but this is soon followed by a condition of depression, or even of coma, for the quantity of carbonic acid produced in the system is now so great that the lungs are wholly inadequate to effect its removal, and all the symptoms of poisoning by carbonic acid come on.

The introduction of air into the system is, to a certain extent, automatic, and, to a certain extent, dependent on the will. In tranquil respiration we are wholly unconscious of the motion; the exciting impression is made on the pneumogastric nerves, and, being conveyed to the respiratory ganglion, the medulla oblongata, is there so reflected that through the agency of the phrenic nerve motion takes place in the diaphragm. The automatic, and therefore unconscious movement, to a certain extent, occurs in that way. But there is no doubt that the brain also participates in the function. No other evidence of this is required than that we can "hold the breath," and the relative share that the voluntary and automatic mechanisms take is illustrated by the circumstance that this holding of the breath can only be persisted in for a certain time, when the necessity for respiring becomes altogether uncontrollable.

It is not, however, to be supposed that so important a condition as that of the introduction of the air is only slenderly provided for. Many other nerves, besides those mentioned, take part in it directly or indirectly; the fifth pair, the nerves of the general surface, and also the great sympathetic, the intercostals, the spinal accessory, which probably gives its motor property to the pneumogastric. Opinion has differed respecting the cause which produces the necessary impression on the

What of protoxide of nitrogen or oxygen? To what extent is the introduction of air dependent on the will? What are the nerves involved in respiration?

receiving nerves, some referring it to the presence of venous blood in the capillaries of the lungs, and some to the carbonic acid in the cells. Moreover, there is reason to believe that the presence of an abnormal amount of venous blood in the respiratory ganglia will of itself give rise to respiratory movements through the proper centrifugal nerves.

The control possessed by the will over the introduction of air stands in a close relation to the production of articulate or other sounds, and therefore to intercommunication between individuals by speech. This involves not merely a general control alone, but also a particular one, reached by regulating the movements of the glottis by the agency of the superior and inferior laryngeal nerves. But though the will for these important purposes exercises so marked a power of regulation, it is to be looked upon as superadded or incidental, and during sleep, coma, and that larger portion of life spent in total inattention to the carrying on of this function, it is discharged in a purely automatic way.

The mechanism that accomplishes the surprising results of respiration may therefore well challenge our admiration. As a self-acting or automatic contrivance, over which we have not a necessary control, it originates in a single year nearly nine millions of separate motions of breathing. It never fatigues us; indeed, we are never conscious of its action. In the same time, a hundred thousand cubic feet of air have been introduced and expelled, and more than thirty-five hundred tons of blood have been aerated. In a future page we shall have to present the wonderful mechanism by which aerial currents, as they pass in and out of the respiratory apparatus, are incidentally employed as a means of producing musical notes or articulate sounds, and of thus establishing a relation and communication between different individuals. By these the feelings and thoughts are diffused, and in a mechanical origin commence those bonds which hold society together.

How is it that the necessary impression is made on them? How are the movements of the glottis regulated? Under what circumstances is respiration purely automatic? How many respiratory movements are made in a year? In that time how much air has been used, and how much blood aerated?

CHAPTER X.

OF ANIMAL HEAT.

Participation of Organic Forms in external Variations of Temperature.—Mechanism for counterbalancing these Variations.—Development of Heat in Plants at Germination and Inflorescence.—Connection of Respiration and Heat.—Temperature of Man.—His Power of Resistance.—The diurnal Variations of Heat.—Annual Variations of Heat.—Control over them by Food, Clothing, and Shelter.—Source of Animal Heat.—Hibernation.—Starvation.—Artificial Reduction of Temperature by Blood-letting.—Principles of Reduction of Temperature.—Their Balance with the Heating Processes.—Local Variations eliminated by the Circulation.—Control by the Nervous System.—Its Physical Nature.—Allotropism of Organic Bodies.

Owing to the earth's diurnal rotation on its axis, and its annual movement of translation round the sun in an orbit inclined to the equator, variations of temperature arise, the vicissitudes of summer and winter, day and night.

In these variations all objects upon the surface of the planet participate; organic forms are no exception. As the heat of the medium in which they live ascends or descends, theirs follows it at a rate dependent on their conductibility.

Like mineral substances, the more lowly forms of life submit to these changes. They have no provision for check or compensation. In summer, the temperature of the stem of a tree rises without any restraint; in winter it declines; and, should the point be reached at which those nutritive changes that give motion to the sap cease, nothing is done to arrest the descent, and the

Are organic forms affected by external variations of heat? What is the consequence in the case of plants during winter?

whole organism passes into a state of torpor, hybernation, or temporary death.

Now, since this following of atmospheric temperatures must take place in every organism as well as in every mineral body, the construction of one having a uniform mode of existence in all climates and all seasons implies a resort to some subsidiary mechanism, which, though it may not check, may yet compensate for these vicissitudes. Accordingly, so nearly is this equalization accomplished in the highly-developed tribes, and a standard temperature so nearly attained for them, that many physiologists, misled by imperfect observations, have concluded that such living beings are emancipated by nature from the operation of physical laws: an erroneous conclusion, for in them that action is only concealed.

In different races, the mechanism by which these variations of atmospheric temperature are balanced acts with different degrees of perfection. On this a subdivision has been founded, and animals classified as the cold and hot blooded. We are not, however, to attach much importance to such an arrangement: it is rather imaginary than founded on any real distinction. In man, the temperature is near 100°; in fishes, it is about that of the water in which they live. Insects, in their larva and pupa condition, are cold-blooded; in their perfect condition, hot.

We have now to explain what physical principles are resorted to in solving the problem of maintaining an organic form at a constant temperature in a medium the heat of which is variable; and as we may reasonably anticipate that these principles are the same in every tribe of life, it will facilitate our investigations to commence with the simplest cases first.

There are two periods in the life of a plant during which it simulates the functions of an animal in maintaining a temperature higher than that of the surrounding air. These periods are, 1st, at the germination of the seed; 2d, during the functional activity of the flower.

If a mass of seeds be laid together, as in the making

What error has arisen from the perfection of compensation in the higher animals? Into what two classes are animals divided? What two periods are there in the life of plants when they act like animals?

of malt, the operation being conducted at a gentle temperature, and with the access of atmospheric air, oxygen disappears, carbonic acid is set free, and the temperature rises forty or fifty degrees. A process of oxidation must therefore have been carried into effect, and to it we trace the heat disengaged, for carbon can not produce carbonic acid without a rise of temperature ensuing. The loss of weight exhibited by a seed is therefore due to its loss of carbon, and the whole effect is explained in the statement that atmospheric oxygen has united to a portion of carbon contained in the seed, producing carbonic acid gas and an evolution of heat.

Again, during flowering, the same action is repeated. The flower removes from the surrounding air a portion of the oxygen it contains, and replaces it with carbonic acid, the temperature rising, as accurate experiments have proved, in absolute correspondence to the quantity of oxygen consumed. Nor is this elevation insignificant. A mass of flowers has been observed to raise the thermometer from 66° to 121°.

If thus the disengagement of warmth is the result of oxidation, it must depend on the presence of air, and be regulated by the rapidity with which oxygen can be supplied. As we pass from the consideration of plants to that of animals, we discover that the production of heat must be connected with the power of the respiratory apparatus, for it is through its agency that air is introduced. Extensive observation accordingly establishes a close correspondence in each animal tribe between the quantity of heat produced and the capability of respiratory apparatus. The lower tribes breathe slowly and are cold. Earthworms are only a degree or two warmer than the ground; and even among vertebrates, fishes are only two or three degrees warmer than the water, a lowness of temperature in a great measure depending on the high cooling agencies that water exerts, its specific heat, and the facility with which currents are established in it. However, even in these cases the production of heat depends on the power of the respiratory engine. The bonito can keep its

Describe the effect during germination. Describe that during inflorescence. On what does the disengagement of heat depend? Give examples of the temperature of the lower animals.

heat 20° above that of the sea, and the narwhal maintains a steady temperature at 96°.

The organic operations involved in nutrition, and also the retrograde changes of decay, can only go on at their accustomed rates so long as standard limits of temperature are observed. The proper progress of the actions of life implies a corresponding adjustment of heat, and this irrespective of the mere size of the animal. Even those that are microscopic must come under this rule. When the temperature of a liquid containing infusorials is caused to descend to the freezing point gradually, the last portions that solidify are those surrounding each of these little forms; a drop is kept liquid by the heat they disengage. In the same individual, the absolute temperature will depend on its respiratory condition; thus insects, in passing through each of their stages of metamorphosis, present a definite condition as to their heat: the larva of the bee may be only two degrees above the air, while the perfect insect is 10°. Whatever accelerates the introduction and expulsion of the air, increases the warmth; so a bee shaken in a bottle, and kept in a state of constant muscular exertion, will raise the temperature contained therein far higher than if he remains inactive. Among insects, those having the largest organs of respiration have always the highest temperature; and, since muscular motion implies destruction of muscular tissue by oxidation, and therefore development of heat, we should expect to find, as is actually the case, that animals possessing the highest powers of locomotion will possess also the highest temperature. Of all, therefore, birds, the endurance and energy of whose powers of flight result from the perfection of their respiratory mechanism, have the highest temperature. It is about 110°. Yet even here there are differences: the sluggish barn-door fowl has not the heat of the energetic swallow.

The standard temperature of man is usually stated to be 98°, but from this mean it ranges within certain limits upward and down. Much depends on the state of the health; of course, every thing on the respiration. In fevers it will rise to 105°; in tetanus it may reach

What is to be remarked in the case of infusorials? How is it among insects and birds? What is the temperature of man?

110°; the contrary in asthma, when it may sink to 82°, owing to imperfect access of air; in cyanosis to 77°, owing to imperfect aeration of the blood; in Asiatic cholera to 75°, owing to the non-reception of oxygen by the discs in their diseased state. It also varies with the period of life: in the new-born infant it is 100°; it presently sinks to 99°, and rises during childhood to 102°. Mental exercise in the adult increases it, bodily exertion still more. The special degree varies with the point on which the observation is made: the limbs are colder than the trunk, and this is the more marked as the point is more remote. On the leg the temperature may be 93°; on the sole of the foot, 90°; while that of the viscera is 101°.

In his residence in different climates, man is exposed to variations of temperature extending over a scale of 200°. Toward the poles the cold of winter is often −60°; in the tropics the heat of summer +130°. For a short period his power of resistance is greatly beyond what these numbers would indicate; he can enter with impunity an oven heated to 600°, provided the air is dry. In these cases, though excessive evaporation from the skin moderates the effect and keeps it within bounds, there is always a marked rise of temperature of the whole body. In a corresponding manner, exposure to cold produces depression.

Among these variations there is one class calling for critical attention. It is the diurnal variation; less marked in man, who instinctively makes provision against it, but well shown in the case of fasting animals. This illustrates, in an interesting manner, the controlling influence of external conditions; for if exposure to a high temperature, as that of an oven, compels a rise of the heat of the whole body, in spite of the conservative arrangements, and exposure to extreme cold compels a descent, we ought to expect that exposure to more moderate degrees would, in like manner, produce an impression.

The old astrologers were therefore not altogether wrong when they affirmed the doctrine of planetary in-

How may it vary in disease? What is the effect in different climates? How is it in artificial extremes of temperature? Do the diurnal variations of heat affect man?

fluences. The diurnal temperatures of a locality, as dependent on the position of the sun, are exhibited in the system of man. The minimum of heat for the night, and the maximum for the day, find a correspondence in the decline of animal temperature at the former, and its rise at the latter period. Experiments on birds submitted to absolute starvation show that, though in their normal state, at the commencement, the variation between midnight and noon was only 1½°, it gradually increased to 6°, until at last, the generation of heat wholly ceasing, the temperature gave way rapidly just previously to death.

If, therefore, it were possible for life to continue without the evolution of animal heat, it would be with the body as it is with the stem of a tree. It would follow the thermometric variations in the air, the maxima of heat and cold being somewhat later than the aerial ones, and within narrower limits, by reason of the low conducting power. The nearest approach to this is in cases of absolute starvation, and though in man the effect is masked by the due taking of food, it none the less exists. In human communities there is some reason beyond mere custom which has led to the mode of distributing the daily meals. A savage may dispatch his gluttonous repast, and then starve for want of food; but the more delicate constitution of the civilized man demands a perfect adjustment of the supply to the wants of the system, and that not only as respects the kind, but also the time. It seems to be against our instinct to commence the morning with a heavy meal. We break fast, as it is significantly termed, but we do no more, postponing the taking of the chief supply until dinner, at the middle or after part of the day. If men were only guided by views of economy of time saved for the pursuits of business, or if, on this occasion, they put in practice the rule they observe on so many others, of never postponing the gratification of their desires, the first affair of the morning would have been an abundant repast. But against this something within us revolts, and that in all classes, the laboring, the intellectual, the idle.

What is the effect on birds during starvation as respects their heat? What is the effect of food in the adjustment of temperature? Why is a light meal taken in the morning?

I think there are many reasons for supposing, when we recall the time that must elapse between the taking of food and the completion of respiratory digestion, that this distribution of meals is not so much a matter of custom as an instinctive preparation for the systemic rise and fall of temperature attending on the maxima and minima of daily heat. The light breakfast has a preparatory reference to noonday, the solid dinner to midnight.

Once more I would remark, that we must not be deceived by the masked aspect the system in this matter presents. Its diurnal variations are concealed by agencies brought specially into operation for that purpose, but they exist in the physical necessities of the case; and herein, I believe, we have a first glimpse of the cause of those periodicities, remarked by physicians from the earliest times; for, though the nervous system, both in a state of health and disease, may seem to be their origin, it is not impossible that its changes are connected with variations thus taking place in the external world.

We have next to consider the effect of the annual variations of temperature, which reach their maximum soon after mid-summer and their minimum soon after mid-winter, the manner in which the system comports itself under them, and the means which instinct and experience teach us to employ in providing against them.

These annual variations of external temperature are chiefly combated by food, clothing, and shelter. The dietetic changes we make between winter and summer are founded upon the principle of using more combustible food for the former, and less combustible for the latter season: and, since the calorific effect of an article of food greatly depends on the quantity of oxidizable hydrogen it contains, the winter diet has more of that element than the summer. Partly thus by varying the nature, and partly by varying the quantity of the food, we can effect a compensation to a certain extent.

Of the manner in which the diet-compensation is aided by variations in clothing little needs to be said. The experiments of Count Rumford established the fact that

To what source may the periodicities of the body be traced? How are annual variations of temperature accounted for?

the conductibility of summer clothing is greater than that of winter, and therefore its resistance to the escape of heat is less. It is sufficient merely to allude to the control gained by difference of thickness in the garments, and by their amount or quantity. We instinctively make these adjustments to meet the existing exigencies, and, as far as may be, in this manner aim at a medium effect.

The check upon external temperature by the use of clothing was doubtless one of the first contrivances of the human race. Even of savage life it is a cardinal feature. The check by adjustment of diet belongs to a civilized state, since it implies a certain control over the animal appetite and personal self-denial. Though great improvements in both of these will doubtless hereafter be made, when the principles of their operation are more generally and better understood, they must, even in their present condition, be regarded as having reached a higher perfection than the check by resorting to shelter. The art of constructing dwelling-houses may be said to be still in its infancy in all parts of the world, and yet in no particular is the physical condition of females and children, and especially of the sick, more nearly touched. It is only in our own times that attention has been drawn to the proper methods for the admission of warmth, and air, and light; the hygienic influences of furniture and decoration are unknown, beyond, perhaps a popular impression that it is unhealthy to be in a recently-painted apartment, inexpedient to sleep in a chamber where there are flowers, and unpleasant in summer to have a carpet on the floor, because it looks warm, and is thought to generate dust. The owner of a palace, on which wealth has been fruitlessly lavished, finds, on a cold day, that he can not obtain from his parlor fire the necessary warmth unless by alternately turning round and round. The testy valetudinarian sits in his easy-chair, tormented by drafts coming in from every quarter. In his vain attempts to stop the offending crevices, it never occurs to him that his chimney is a great exhausting machine, drawing the air out of the

What is the conclusion drawn from Rumford's experiments on clothing? What is the degree of perfection attained in compensations of animal heat by shelter?

room, and that his means of warming and ventilation are the most miserable that could be resorted to, since radiation can warm only one side of a thing at a time, and fresh air under those conditions can only be introduced by drafts.

To warm rooms by contrivances such as the open fireplace or stove is obviously unphilosophical, since the effect of these is to exhaust the air of the apartment. The modern method of warming by furnaces, which act by throwing air duly moistened and of the right temperature into the rooms, and therefore by condensation, is clearly a better system, since it not only puts an end to all drafts, the tendency being to force air out through every crevice instead of drawing it in, but it possesses the inappreciable advantages of giving uniformity of warmth, a perfect control over the degree of heat, and likewise over the nature of the air, which need not be drawn from the cellar, or the contaminated impurity of the street, but by suitable flues from the free and clear air above. Ventilating contrivances to force a supply of artificially cooled air in the summer, and warm air in the winter, into dwelling-houses, are still a great desideratum.

By the aid of diet, clothing, and shelter, we are able to effect an almost complete compensation for the changes of diurnal and annual temperatures, and even to occupy any climate of the globe. It is the management of caloric that makes man what he is, and constitutes his special prerogative; his degree of skill therein is the measure of his civilization. The distribution of plants and animals, or, rather, their limitation within fixed boundaries, depends on the distribution of heat, but from these restraints man is free, because he can control temperatures.

From these considerations of the effect of external heat on the human mechanism, we return to a more critical examination of the modes by which heat is generated, and its degree regulated in the body.

In every instance we assert that the production of animal heat is due to oxidation taking place in the econ-

What is the best system of warming dwellings yet introduced? In what respects is it very imperfect? Do any other animals participate with man in the power of controlling heat?

omy, and giving rise to carbonic acid, water, and other collateral products.

Reduced to its ultimate conditions, the evolution of animal heat depends on the reaction taking place between the air introduced by respiration and the food, and as either one or other of these is touched, the result may be predicted. If, for example, into the digestive canal alcoholic preparations be introduced, they are absorbed, by reason of their liquid condition and diffusibility, with readiness. The combustibility of alcohol, and the amount of heat it yields, are so great, that the primary effect of the oxidation is a warmth or feverish sensation. By reason of the changes now taking place so actively in it, the blood circulates with unwonted rapidity, and the supply to the brain increasing, that organ exhibits an unusual functional activity. But this display of intellection is only temporary, and an opposite condition soon comes on, for, more carbonic acid accumulating in the blood than the lungs can get rid of, the depressing effects of that body commence, and eventually the symptoms of poisoning by it ensue.

Not unlike this is the train of effects arising when, instead of varying the nature of the article ingested, we vary that of the gas respired. An energetic supporter of combustion, like the protoxide of nitrogen, gives rise to a feverish glow, cerebral activity, to be followed eventually by a deep depression, the poisonous influence of the carbonic acid produced being exhibited. After a while the system casts it off, and recovers its condition of health completely. If there be an abstinence from food, since the introduction of air by respiration goes on without abatement, the body itself must undergo oxidation, lose weight, and emaciation occur. Its tendency to follow the diurnal variations of temperature becomes more and more strikingly marked as the process of starvation goes on, and finally a rapid and unchecked decline of the heat ensues. Yet even then life may be preserved by the application of sufficient external warmth, and from an extreme condition of attenuation an animal may be rescued by the use of food; but for

What is the effect of more combustible aliment? What of more energetic supporters of respiration? In cases of complete starvation, what effect is there on the temperature?

such a recovery the external warmth must be continued until there has been time for digestion and absorption to take place. If, however, such an extraneous aid be not duly applied, the temperature of the starving animal goes on diminishing, and he dies of cold.

The doctrine we are here inculcating, that animal heat is due to oxidation in the system, is still farther strikingly illustrated by what might be termed starving the respiration. As cold is felt from want of food, so also it is from want of air. In ascending high mountains, the effect upon the system has been graphically expressed as "a cold to the marrow of the bones;" a difficulty of making muscular exertion is experienced; the strongest man can scarcely take a few steps without resting; the operations of the brain are interfered with; there is a propensity to sleep. The explanation of all this is very clear. In the accustomed volume of air received at each inspiration there is a less quantity of oxygen in proportion as the altitude gained is higher. Fires can scarce be made to burn on such mountain-tops; the air is too thin and rare to support them; and so those combustions, which should go on at a measured rate in the interior of the body, are greatly reduced in intensity, and hence the sense of a penetrating cold. Such journeys, moreover, illustrate how completely the action of the muscular system, and also of the brain, is dependent on the introduction of air; and under the opposite condition of things, where men descend in diving-bells, though surrounded by the chilly influences of the water, they experience no corresponding sensation of cold, because they are breathing a compressed and condensed atmosphere.

The respiratory apparatus of certain animals permits a reduction in the amount of air introduced under exposure to a due degree of cold. Such animals are said to hibernate. At the coming on of winter their adipose tissues are engorged with fat. As they pass into their annual sleep, the rate of their respiration falls. The marmot, which in activity will make 140 respirations in a minute, makes now but 3 or 4; the temperature of the body descends, and combustion of the store of fat goes

What are the physiological consequences of breathing a very rarefied air? What phenomena are displayed by hibernating animals?

on more slowly. Yet it does go on, for, toward spring, the animal has become very lean; sufficient heat is disengaged to permit the blood slowly to circulate, and so barely to keep up the functions of life. If, however, the stock of material available for combustion is insufficient, the animal dies.

Although we can not interfere with the rate of respiration, we can affect the quantity of air introduced into the system by artificial means, as in the operation of blood-letting; for though, after blood has been drawn, we may make the normal number of respirations, 17 in a minute, and for each introduce 17 cubic inches of air, we have diminished the number of discs, the carriers of oxygen; and, as the experience of physicians in all times has shown, there is no method so effectual in reducing any unusual or febrile temperature. So, in like manner, in Asiatic cholera, the marble coldness the body presents is attributable to the loss of function of the discs, and the consequent abatement in the quantity of oxygen introduced.

Thus far we have considered the means the animal mechanism possesses for raising its own temperature; it remains to show how it can also regulate it. For any thing that has thus far been said to the contrary, the combustions or oxidations continually going forward should establish a constant rise, and there must therefore be some principle of restraining such a rise within due bounds. Considering also the incessant vicissitudes of atmospheric temperature, a constant degree could not be maintained unless the system possessed the means of depressing as well as elevating its heat.

That the means of regulating the heat are purely physical, we should expect for many very obvious reasons. Economy of heat is accomplished by non-conducting material. On this principle, hair, wool, and feathers act by excluding the contact of the atmosphere, their low conductibility being brought into operation. In many cases, the manner in which this is done is clearly intentional. Thus the down placed on the breast of a water-fowl is to screen off the chilling influence of the

Can the temperature be reduced by interfering with the circulation? In what manner does the abstraction of blood act? Mention certain physical means for regulating animal heat.

water, which is there chiefly felt as the bird swims on the surface. The deposits of fat in whales, their blubber, at once affords a protection through its imperfect conductibility, and is also a store of combustible material for the purpose of respiration.

The chief cooling agencies in animals are, 1st. Radiation; 2d. Loss of heat by warming the expired air; 3d. Loss by contact of the cold external air; 4th. Evaporation. The circulation of the blood tends to establish an interior equalization, so that local variations are soon obliterated; for, through whatever part the blood may flow, it attains the temperature thereof, and, passing in succession from part to part, equalizes the heat of all.

It would be useless to offer any proof that a living being, like an inorganic mass, loses or gains heat, as the case may be, by radiation. Since, however, in man, the temperature is usually higher than that of the surrounding medium, the result of this action is that cooling takes place. With regard to loss of heat by warming the expired air, it may be observed that, whatever the temperature of the external air may be, it is raised to that of the lungs after it has been brought into the respiratory passages. This constitutes, therefore, a cooling agency of variable power, for the loss will be greater as the external heat is lower: if the atmospheric temperature rose to 98°, loss in this manner would cease. Recalling what has been said respecting the mode in which air is introduced, it is plain that this loss will chiefly fall upon the nasal passages, the trachea, and larger ramifications of the bronchial tubes; for, by the time the volume inspired has made its way beyond that limit, its temperature must be nearly that of the body. The contact of the cold surrounding air, and more particularly of currents occurring in it, act chiefly upon the skin, and it is in preventing this loss that clothing becomes so efficient. The difference we so frequently notice between the indications of the thermometer and our own sensations are, for the most part, dependent on these currents. A temperature of 50° below zero can be sustained without much inconvenience if the air is perfectly calm, but not so if there is any wind. Of all the cooling agencies,

What are the chief cooling agencies? How is it that heat is lost by radiation and contact?

evaporation is, however, by far the most energetic. From the skin and the air cavities, large quantities of the vapor of water are exhaled. As the external heat rises, the sudoriparous tubes act with increased energy, and pour out their excretion as drops of sweat faster than it can be removed. Their length has been estimated at 28 miles. Since, at the temperature of the body, the heat of elasticity of the vapor of water is 1114°, this continued vaporization from the skin and lungs is one of the most powerful sources of refrigeration.

It may be well to direct a closer attention to the special action of the air passages and skin as concerned in these cooling processes. The diurnal loss of water, by both organs conjointly, is usually estimated at 3½ lbs., of which the pulmonary exhalation constitutes about one third, and the cutaneous about two thirds. The skin acts in a variable manner, losing more or less water as the external air is dryer or more damp. The removal of water therefore becomes a complex operation, in which three different organs are concerned—the skin, the lungs, and the kidneys. Of these, the skin acts meteorologically and variably, as has been just remarked, and the respiratory organs for the most part uniformly. But since it is requisite, in the normal operations of the system, that the diurnal average of water should be removed, the variable action of the skin throws a variable action upon the kidneys, for the excess that the skin can not evaporate must be strained off by these organs. In this regard the kidneys act, therefore, vicariously for the skin; and in hot weather, when the cutaneous losses are great, but little urine is discharged; but in cold weather, when the cutaneous loss is diminished, its quantity is increased.

I think, however, that as regards the respiratory organs, a distinction should be made in their mode of action. In reality, they operate in a double way. 1st. They act, so far as the nasal passages, the trachea, and larger ramifications of the bronchial tubes are concerned,

Of all cooling agents, which is the most effectual? What is the amount of heat lost in evaporation? Describe the action of the skin. What is meant by the vicarious action of the kidneys? How is it that the respiratory organs operate in this respect in a double way?

meteorologically, and therefore variably, for the introduced air possesses the existing atmospheric temperature; is at one time warm, and at another cold; yet, since it always leaves these passages at 94°, it removes from their surfaces sometimes less and sometimes more heat; but it is not so with the action going on in the air-cells, the temperature of which, and of the air they contain, is always uniform; and as water vaporizes into them, it must always do it at a uniform rate, and remove as its caloric of elasticity a uniform amount of heat. I therefore decompose the loss of heat by the respiratory organs into two portions: one, which is constant, and taking place in the cells; the other, variable, occurring in the large air-ways, and, being meteorological, coincides in this respect with the cutaneous loss. In considering the diseases of the respiratory organs, it is well to keep this distinction in mind.

The establishment of the equilibrium of temperature in an animal is effected by the mutual operation of the heating and cooling arrangements. More or less heat, as the system requires, may be furnished by promoting or retarding the oxidation of respiratory material; and since a living being, like an inorganic mass, is subject to every external influence, its temperature tending to rise or fall, as diurnal, or annual, or seasonal changes may be, these, as well as its own interior variations, are held in check by the cooling or warming powers it can exert. Local differences within itself are eliminated in an indirect, but still very effectual manner, by the circulation of the blood; and, considering the range of variation to which it is exposed, and the frequency of the changes, the required equilibrium is admirably secured.

I have reserved for a more special and prominent consideration the influence exerted by the nervous system over animal heat, since it is upon this that many have been disposed to deny the great truth that the heat of the body arises from oxidation. They say that it is produced by the nerves. Even a mental emotion gives rise to disturbance of temperature, and the face may be covered with blushes. Moreover, as experiments have proved, on cutting a nerve the temperature of the parts

How is it that the balance of temperature is attained? Has the nervous system any control?

it supplies declines; on injuring the great nerve centres the temperature of the whole system lowers, even though artificial respiration may be kept up. In cases of paralysis, the temperature of the disabled part may be very much lower than that of the sound. A paralyzed arm has shown a surface heat of 70° only, while the sound one has been at 92°. It is also said of decapitated animals that they cool quicker when artificial respiration is kept up than when they are let alone.

All this may be very true, yet it is very far from proving that the nerves are the generators of animal heat. The engineer of a locomotive can regulate the speed of his train and control the production of steam by throwing more or less fuel on the fire, or by supplying it with more or less air; but does any one impute the production of the heat to him? If an accident should throw him off, thereby establishing a sort of analogy between his machine and the decapitated animals we have referred to, the stoppage that would soon ensue, and the dying out of the fire, would by no means prove that he made the heat!

And so with the nervous system, its function is not a generative, but a controlling one. It determines in what way the combustive or oxidizing actions shall go on, but that is a totally different affair from forming the heat.

Before specifying more particularly the views I entertain on this subject, I will remark, that the most superficial consideration satisfies us that oxidation in the system goes on in a regulated way. There is not an indiscriminate attack made by the arterial blood on whatever is next before it, but those particles only are removed which the needs of the system require. This therefore implies some overriding or superintending agency, that can save one atom from destruction and surrender another. The portion assaulted may, to all appearances, be identical in physical aspect and chemical constitution with an adjacent one that is passed by. There seems to be an arrest or suspension of affinity in one case, and its ready satisfaction in the other.

There are some well-known facts in natural philosophy which throw a flood of light on this obscurity. If

What is observed in cases of paralysis? Is the function of the nervous system generative or controlling?

a piece of pure zinc be placed in a glass of acidulated water beside a piece of copper, so long as the metals are kept apart no action whatever ensues; but if a conducting thread is laid from one to the other, the zinc instantly begins to oxidize, clouds of hydrogen gas bubbles rise from the copper, and the thread becomes at once red-hot and magnetic. On lifting the communicating thread all these actions cease; on restoring it they instantly recur. We think we explain them by saying that they are all due to the decomposition of water by the zinc. But why was the zinc passive when alone, and why did it assume this activity when merely touched by another metal? Does not all this serve to show that substances may be, as it were, in a quiescent state, and on the application of what may perhaps seem the most insignificant cause, may suddenly assume activity, and forthwith satisfy their chemical affinities? There is nothing in the graduated oxidations going on in the system more obscure or more unaccountable than the phenomena of a simple Voltaic circle. Their effects are almost parallel.

All elementary substances appear to have the quality of assuming active and passive conditions. Carbon, moreover, presents many intermediate forms. As diamond it is extremely incombustible, and is set on fire with difficulty even in oxygen gas; as lampblack it will kindle spontaneously. With these differences in its relations with oxygen, it also exhibits great variations in its optical, calorific, mechanical, and other properties. These transitions of state may be induced by various causes, especially by the agency of what are called the imponderable principles, as by rise of temperature, and exposure to the sun-light. Thus, in the case of chlorine, I have shown that, though it refuses to combine with hydrogen so long as it is in the dark, an exposure to indigo-colored light will cause it to unite with explosive energy with that substance; and these peculiarities are retained by bodies when they go into union with each other.

The properties here spoken of have been designated

How may the controlling action of the nervous system be illustrated by electrical experiment? Give an example of the active and passive forms of bodies. How may these transitions of form be accomplished?

by Berzelius as the allotropism of bodies. I have endeavored to prove that allotropism is the true cause of many of the obscure facts we meet with in the animal mechanism; for it is very clear that something so modifies the relations of the tissues to oxygen that they are not indiscriminately destroyed by it, but these parts yield in a measured or regulated way; and since, in inorganic substances, the influence of the imponderables can compel the assumption of an active or passive state, there is nothing contradictory in imputing to the nervous system a similar power.

In this manner we may therefore conclude that, so far as tissue destruction is concerned, the nervous system possesses a governing or controlling power; that by keeping parts in states answering to the passive and active conditions of inorganic chemistry, it can suspend the action of the respired oxygen or permit it to take effect.

CHAPTER XI.

OF SECRETION.

SEROUS, MUCOUS, AND HEPATIC SECRETIONS.

Object of Secretion.—Type of secreting Mechanism.—Filtration and Cell Action.—Of Serous Membranes and their Secretions.—Of Mucous Membranes and their Secretions.—The Liver: its Development and Structure.—Source, Quantity, Composition, Uses, and Flow of the Bile.—Existence of biliary Ingredients in the Blood.—Production of Sugar and Fat in the Liver.—Changes of the Blood-cells in it.—General Summary of the four-fold Action of the Liver: it produces Sugar and Fat, eliminates Bile, is the Seat of the final Destruction of old Blood-cells, and of the Completion of new Ones.—Of the ductless Glands.—The Spleen: its Functions.

Two classes of substances occur in the blood—the products of decay and the elements of nutrition. The

What designation has been given to such states? What may finally be concluded as respects the action of the nervous system?

equilibrium of the system requires that the former should be removed and the latter appropriated.

The primary object of the function of secretion is this dismissal and appropriation, and therefore, through the latter duty, secretion becomes connected with nutrition.

The elementary type of a gland or organ of secretion consists of a sac, on the interior of the wall of which a network of arterial ramifications is spread; this delivers its blood into a similar network of veins. The matter the gland is destined to separate oozes from the arterial capillaries into the interior of the sac, and is delivered through the neck or mouth thereof, which may be spoken of as the duct.

This elementary or typical form of a gland is but very little departed from when the sac is elongated into a tube; and even where this has been extended to an exaggerated degree, the essential principle of action still remains the same.

From the constancy of aspect presented by glands we might be led at first to suppose that their peculiarities of construction determine their physiological action, that the liver secretes bile, and the kidney urine, because they have the special organization needful for such purposes. Such a supposition, however, has to be received with much limitation, as is proved by numberless cases of vicarious action. Thus, in morbid difficulties of the liver, the skin will discharge its duty for it in the elimination of the bile.

The secretion of material from the blood may be considered as conducted in two different ways; 1st, by filtration; 2d, by cell action.

Secretion by filtration is, of course, a purely physical act. The transudation of water charged with saline substances, or with more or less of albumen, seems to imply nothing but the escape of pre-existing bodies through pervious or porous membranes. Such a result is presented in the case of the lachrymal gland, its duty being to accomplish a definite mechanical operation for the eye in keeping the cornea clear and transparent.

What is the object of the function of secretion? Describe the elementary type of a gland. How do the facts of vicarious action bear on the theory of secretion? In how many modes is secretion accomplished? Give an example of secretion by filtration.

This mechanical function is again observed in the case of the serous membranes, and particularly the synovial ones, in which the relief of friction of movable parts seems to be the object aimed at.

As long as the material secreted clearly pre-exists in the blood, it is needless to refer secretion to any other principle than the simple one of transudation or filtration. It would be unphilosophical to suppose that the lachrymal gland exercises any property for the formation or production of water when by mere transudation copious supplies of that substance can be obtained from the blood.

But secretion is, moreover, perhaps connected with cell life. On the upper part of the intestine of the young chick, a few cells make their appearance about the fourth day of incubation. They are eventually recognized as bile-containing cells from the color of their contents. As the process goes on, the spot they occupy buds off, as it were, so as to produce a blind pouch. This offshoot, with its exterior cells, is eventually, when perfect development is reached, the liver.

Our conclusion respecting the mode of action of secreting cells turns altogether upon the evidence of the power they possess of preparing material not pre-existing in the blood. Thus, if it should be shown that, under normal circumstances, the elements of bile are not found in the blood, the inference might be drawn that the hepatic cells display a combining, or, as it were, a preparing power; and so likewise in the case of other secreting cells; but the weight to be attached to such evidence is greatly affected by the consideration that the action of each gland or secreting apparatus masks what is really going on in the system. It is possible that we may be scarcely able to discover the traces of substances in the blood, and yet a tendency may exist for their accumulation to a great extent. Thus there can be no doubt that urea would abound through the disintegration of the muscular structures, and the use of nitrogenized food, if it were not for the action of the kidneys. It is the very perfection of that action which so diminishes the amount in the circulation as to prevent

Give an example of secretion by cell action. Why is it so frequently difficult to detect the products of secretion in the blood?

us, except with difficulty, from detecting the presence of the ingredient.

The cases in which the influence of cells is indisputable are those offering to us combinations of progressive metamorphosis. Of these, the most striking instance is the preparation of the spermatic fluid. Perhaps we should not be very far from the truth if we considered all those secretions in which the materials are in a state of retrograde metamorphosis, or in a descending career, as arising by mere filtration, and those ascending to a higher grade as due to cell agency; between the two there being an intermediate class, the phase of which is stationary, and cells may or may not be necessarily involved, as, for instance, the transmutation of one fat into another, or the preparation of sugar from albuminoid bodies.

The apparatus for secretion is generally conveniently treated of under two heads: 1st. Membranes, such as the serous and mucous; 2d. Glands, as the liver, kidney. This division is, however, not founded either on structural or functional differences, and is to be preserved merely for the sake of convenience.

A secreting membrane consists essentially of a tunic of connective tissue, affording a nidus for vessels and nerves. Upon this, in the opinion of many anatomists, a thin basement membrane is laid, its existence being, however, denied by others. Upon the surface of the basement membrane there is a layer of cells, differing in form and arrangement in different regions. In some places the cells are flat, in others cylindroid. Their duration is temporary, one brood succeeding another from germs in the basement membrane. The superficial, and, therefore, the older cells, desquamate or deliquesce, and are replaced by others from beneath.

The fluid exuding from serous surfaces is a dilute albuminous solution, more dilute as it is presented in the ventricles of the brain, and more concentrated in the synovial cavities, its consistency in the latter case being such that it may sometimes be drawn out in tenacious

What are probably the conditions for filtration and cell action respectively? How many forms of apparatus for secretion are there? Describe a secreting membrane. What are the properties of the fluid secreted by serous surfaces?

threads. The mechanical qualities of these various exudations permit a certain freedom of motion in the parts to which they are applied. Thus the secretion of the peritoneum facilitates the movements of the abdominal viscera; those of the pericardium and pleura, of the heart and lungs; those of the synovial membranes and bursæ mucosæ, of the joints and tendons.

Among secreting surfaces the mucous membranes are usually enumerated. Strictly speaking, however, they are scarcely so much secreting surfaces as the seat of numberless secreting organisms. They line the interior of the digestive, respiratory, urinary, and generative apparatuses, and are characterized by extreme vascularity. In structure they consist of several different layers or regions, the undermost being submucous cellular tissue, upon which is spread the proper mucous membrane, containing connective and elastic tissue, affording a nidus for blood-vessels and nerves. Upon this is the basement membrane, covered with epithelial cells. In many regions this compound structure rises into elevations, as in the intestinal villi, or sinks into depressions, as in the follicles.

It is not necessary to give a detailed description of mucous surfaces farther than to state that from them there is furnished a viscid, glairy fluid, of different shades of color from white to yellow, denser than water, and insoluble therein. Examined by the microscope, it contains granular corpuscles and epithelial cells. Its reaction is alkaline, and its proximate constituent is a substance to which the name of mucin has been given. Derived from different sources, as the nasal, bronchial, and pulmonary surfaces, the intestinal canal, and the urinary and gall bladders, it exhibits specific differences.

Of secreting Glands.—The typical form of secreting cell-gland is a single cell, with its nucleus at the lower end, the other end having become open by deliquescence or dehiscence, and thus constituting a sac. From the nucleus thus situated at the end of the cavity broods of young cells arise. These become more perfect as they advance toward the mouth of the sac. The outer wall,

What are mucous membranes? What are the properties of mucus? Describe the typical form of a secreting cell-gland.

and especially the region of the nucleus, is furnished copiously with blood-vessels.

Of such structures, variously modified, different glands are composed. We shall now proceed to the description of the more important of these, as the liver, mammary gland, etc.

OF THE LIVER.

The first appearance of a bile-secreting organ is the occurrence of yellow cells variously scattered upon the lining membrane of the digestive cavity, as in the hydra. A concentration or localization next ensues, such yellow cells being grouped upon the wall of the intestine at a definite spot. A cæcal projection, in the higher tribes, seems next to force out the yellow cells, bearing them on its exterior, as in the nudibranchiate gasteropods; and as these cæca are prolonged more and more, so, in a more definite manner, does the rudimentary liver appear.

The comparative anatomy of the liver is repeated in its order of development in the high vertebrated animals. In them it is first detected in an evolution of cells upon the intestinal wall, at the point eventually to be the place of discharge of the common bile-duct. This agglomeration of bile-cells is next seen to project or bud off through the intrusion of a cæcal pouch. In the amphioxus the condition thus reached remains permanent, and is the counterpart of the liver of a fowl about the fourth day of incubation. The cæcal pouch next sends forth ramifications, likewise accommodated with cells, and these, branching again, give origin to a complicated structure. In this condition, the mouth of the cæcum is drawn out and narrowed down, and so forms the rudiment of an hepatic duct.

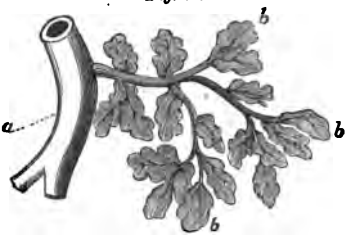
In man, the liver is the largest gland in the body: it is of a reddish-brown color, dense, and from three to five pounds in weight; convex on its upper, and concave on its inferior surface. It has five lobes: the right lobe, the left lobe, the lobus quadratus, the lobus spigelii, and lobus caudatus. It is held in its position by duplicatures of peritoneum and by a fibrous cord termed its liga-

What is the rudimentary form of the liver? In what manner does its development take place? Describe the liver.

ments. Its peritoneal envelope is the cause of its glossy appearance; its cellular envelope extends into the interior as sheaths for the vessels.

The intimate structure of the liver in man is, in many particulars, still imperfectly known, though the attention of the most eminent anatomists has been devoted to it. It may, however, be understood that each hepatic vein, commencing in the substance of the liver, bears upon its capillaries small portions called lobules, from the $\frac{1}{30}$ to the $\frac{1}{40}$ of an inch in diameter, in a manner which calls to mind the arrangement of leaves on a branch, or a bunch of grapes, as represented in *Fig.* 68, *a* being the vein; *b b b*, leaf-like lobules upon its branches. Excluding the lymphatics, it may be said that four different systems of vessels are engaged in the liver—the portal vein and hepatic artery, the bile-ducts and hepatic veins. The first pair are afferent, the second pair efferent vessels. The portal vein brings the blood from which bile is to be secreted; the hepatic artery brings aerated blood for the nourishment of the gland; the bile-ducts carry away the biliary secretion which has been separated from the portal blood, and the residue, taken charge of by the hepatic veins, is eventually carried back into the general circulation through the vena cava.

Fig. 68.



Hepatic veins in the lobules of the liver.

The arrangement of the four systems of vessels is this. The vein originates in the centre of each lobule, and exhibits a ray-like divergence. On the periphery of the lobule the other three vessels ramify. Of these the portal veinlets dip down into the substance of the lobule, as also do the hepatic arteries, but it is not known whether the bile-ducts proceed beyond the surface. The manner in which they are related to the secreting cells, and receive the liquid yielded by them, is a subject of contro-

What is known respecting its intimate structure? How many systems of vessels are found in the liver? Of these, which are afferent and which efferent? What is the function of each?

versy. Nor is it certainly known whether the hepatic artery discharges its blood into the portal capillaries, or into those of the hepatic vein.

The portal blood, as it is preparing to enter the liver, may be regarded as systemic venous blood, the constitution of which has been altered through the additions made to it by absorption of matters from the stomach and intestine. We may overlook for the present those contributions it receives from the veins of the spleen and other sources. Regarding it, therefore, as systemic venous blood, charged with certain of the products of digestion, it enters the liver to be acted upon by that gland. The first effect upon it is, in a chemical point of view, well marked. The stream setting off to the general circulation through the hepatic veins may be said to carry away the whole of the nitrogenized material; for the bile, at this point parted out and sent back to the intestine through the biliary ducts, does not contain more than 4 per cent. of nitrogen, and this exclusive of the water which imparts to it its liquid condition. Arrived in the intestine, a repetition of the same process of partition takes place, the coloring matter containing nearly the whole of this residual nitrogen, being dismissed with the fæces, and the remaining hydrocarbon taken up by the lacteals along with other fats.

The first duty of the liver is therefore a separation of the nitrogenized principles of the portal blood. These are forthwith carried into the general circulation through the hepatic veins and the vena cava. The result is, that there is returned to the intestine a sulphureted hydrocarbon, still containing so much nitrogen as to form a very unstable product, prone even to spontaneous decomposition. In the intestine its nitrogen is wholly removed from it, and the combustible hydrocarbon is then absorbed.

The portal blood, regarded under the aspect here presented, is obviously composed of two constituents: 1st. Systemic venous blood; 2d. Matters obtained from the digestive cavity. We next inquire from which of these the bile is really derived.

What is the portal blood? What is the first effect of the liver upon it? What course is taken by the bile? Of what parts is portal blood composed?

Besides the presumptive evidence arising from the consideration that if the bile originated from matters just absorbed from the digestive cavity, it would be inconceivable why it should be returned forthwith thereto; its quality of extreme instability marks it out as a substance fast approaching to final disorganization and decomposition. It bears no aspect of a histogenetic or formative body, but, on the contrary, it is on the downward course. We should scarcely expect to recognize it as a primary product of the digestive action, but should seek its probable origin in some source of decay.

Whatever weight may attach to such considerations, we have, in addition, direct evidence placing the source of the bile beyond doubt by referring it to the systemic venous blood, and not to the matters just obtained from the digestive cavity.

During fœtal life, the digestive organs are in an inactive state, but the liver, largely developed, discharges its secretion into the intestine. This secretion, known as the meconium, is a true bile.

During fœtal life the liver is therefore discharging the same function that it does after aerial respiration has commenced—that is to say, it secretes bile (meconium) into the intestine; but at this period, since there is no true digestion, the bile can come from one source alone, and that source is the systemic venous blood. There therefore can remain no doubt that, in after life, the same effect takes place, and that the bile is never derived from materials just brought from the digestive cavities.

I therefore regard the bile as an excretion of materials decomposing and ready to be removed from the system. I incline to the supposition that much of it is derived from the cells of the blood, the life of which is only temporary, for the casein of the meconium is nothing but the globulin of the cells, the two substances being chemically allied, and the predominance of iron in the ash of meconium seems to establish a connection with hæmatin.

Bile, from whatever animal it may have been derived,

From which of these is the bile derived? What is meconium? How does the composition of meconium indicate the source of bile? From what source is its iron derived?

contains a resinous soda salt, a coloring material, cholesterine, and mucus. The acid of the soda salt is the taurocholic or glychocolic. The coloring matter in carnivorous and omnivorous animals is brown, the cholepyrrhin of Berzelius; but in birds, fishes, and amphibia, it is green, biliverdin.

Bile is secreted more slowly during a long period of fasting, and more rapidly during normal nutrition. To a certain extent, this variable rate depends on the general principle that a gland acts more energetically in proportion as the supply of blood sent to it is greater. If not wanted for the present purpose, the product is stored up, for a time, in the gall-bladder.

The flow of bile takes place with different degrees of rapidity at different diurnal periods: thus it reaches its maximum in from thirteen to fifteen hours after the last full meal, and then rapidly diminishes.

Bidder and Schmidt estimate the diurnal secretion in an adult at 54 oz., containing 5 per cent. of solid matter, an estimate undoubtedly too high, so far as an average diet and state of health are involved.

But the liver has other duties to discharge besides the separation of bile. It gives origin to sugar and fat, as is proved by the circumstance that the blood of the hepatic veins is richer in those ingredients than the blood of the portal. In this respect its action seems more particularly to be that it converts other sugars into the particular form known as liver-sugar, which it can also produce from the transforming albuminous bodies; it forms fat from sugar, and makes from certain other fats the special one known as liver-fat. In this duty of forming sugar and fat, it exhibits an inverse power of action; as the production of the one predominates, that of the other declines.

Does the liver really secrete bile? Is it the business of the so-called bile-secreting cells to withdraw the constituents of that liquid from the blood, and combine them together into this viscid yellow liquid? I think not; for it is a matter of demonstration that not only

What are the chief ingredients of bile? Under what circumstances does the secretion of bile vary? When is its maximum flow? What is its diurnal amount? What other substances besides bile does the liver secrete?

every constituent of the bile, but the bile itself, pre-exists in the blood, and it is just as unphilosophical to burden those cells with the duty of forming it as it would be to believe that a like agency is needful for the appearance of urea in the kidney.

For such reasons, I believe that the bile simply transudes from the blood, and that the cells of the lobules have no special relation to it beyond this, that it oozes past their interstices, or, perhaps, by physical imbibition, finds access to their interior. I see no reason that these cells should form it when it pre-exists in the blood, nor does the state of the affluent and effluent blood offer any contradiction to this conclusion. In all discussions of the functions of this organ founded upon a comparison of the portal and hepatic venous blood, the relative quantity of water they contain, and its great and even rapid fluctuations, should always be borne in mind. As might be expected, portal blood contains far more water, and, even after abundant drinking, the amount in the hepatic venous blood has by no means increased to the extent that might have been expected. It is for these reasons that the bile varies so greatly at different periods in its specific gravity and fluidity.

The liver, besides producing sugar and fat, is the seat of disintegration of the worn-out blood-cells, and here probably the young ones are pushed forward through a certain stage of their development; advantage, moreover, being incidentally taken of the secreted bile, which possesses properties useful though not essential for promoting the digestion and absorption of fatty material, perhaps, also, of imparting a definite course to the transmutation of the semi-digested material in the intestine, and this both as regards nitrogenized, amylaceous, and fatty bodies. Of the influence of the bile in promoting the absorption of fat, the physical experiments heretofore alluded to leave no doubt; but that these uses are of a secondary or non-essential kind, and are only taken advantage of in an indirectly economical way, is established beyond all possibility of a doubt by the fact that animals can live for a long time, even for months, without the passage of bile into the intestine, provision hav-

Does bile pre-exist in the blood? In what manner is it removed? What action has the liver on old blood cells?

ing been made for its escape externally through an artificial fistulous orifice.

These conclusions respecting the functions of the liver are in harmony with the appearances presented by the blood leaving and entering it: the predominance of colorless blood-cells, and of young cells well advanced toward perfection in the former, and of wasted, worn-out ones in the latter; with the fact that the maximum secretion of bile does not take place until more than half a day after the ingestion of food; and that during fœtal life, in which there is no food, either in the stomach or intestine, to be digested, the liver is nevertheless in high activity, and bile is secreted.

In view of all the preceding facts, we may therefore finally conclude that there are at least four distinct operations conducted in the liver: 1. The production of sugar and fat; 2. The separation of the bile; 3. The destruction of old blood-cells; 4. The completion or perfection of young blood-cells, perhaps by receiving their iron. With respect to these it may be remarked,

First. The formation of sugar and fat, either from carbohydrates, or what, in this instance, is more probable, from albuminoid bodies brought by the portal vein, can no longer be doubted. The prevalence of liver-sugar and liver-fat in all that region of the venous circulation included between the liver and the lungs must be attributed to this source. That the sugar undergoes rapid metamorphosis in the pulmonary organs is plainly proved by the effects of irritation of the pneumogastrics, which, interfering with the function of respiration, permit this substance to reach the aortic circulation, from which it is removed by the kidneys, diabetes arising. So far as the preparation and course of this sugar is concerned, the liver is a ductless gland. The production of fat appears to be inversely as that of sugar.

Second. The bile is separated from the blood portion of the portal blood, and not from the products of digestion obtained from the chylopoietic viscera. The elements of bile pre-exist in the blood, and escape from

What action has the liver upon young blood-cells? Mention the four operations conducted in the liver. In what manner does the sugar produced disappear? How does the bile escape from the portal veinlets into the biliary ducts?

the portal veinlets to the biliary ducts by mere filtration or strainage. The precise source from which the bile is derived is probably the blood-cells, and in the changes they are undergoing the spleen is perhaps concerned. If this be so, the bile-duct is as much a duct for the spleen as it is for the liver itself. The bile may almost be looked upon as a hydrocarbon, containing a very changeable and therefore noxious coloring material; this, when the secretion reaches the intestine, is parted from it and dismissed with the fæces, the proper hydrocarbon being taken up by the absorbing arrangement for hydrocarbons, the lacteals, and so sent through the thoracic duct. Perhaps, also, by reason of its special adaptedness for that purpose, it aids in the absorption of other fats.

At this point it may be remarked that the view here presented of the sugar-forming and bile-straining functions of the liver appears to be greatly strengthened by the anatomical construction of that organ. There is no obvious communication between the portal and hepatic veinlets save through cells, but the portal veins and the bile-ducts run in their ramifications side by side.

Third. Whatever part of the disintegration of old blood-cells takes place in the spleen, their final destruction is doubtless accomplished in the liver, this being the immediate source of the bile itself. Though these metamorphoses are, to a greater or less extent, occurring throughout the circulation, it is in these two great glands that an opportunity is afforded for the destruction to reach its completion, and the resulting product of waste to be removed; nor is there any thing in this view at all contradictory to the opinion that all the constituents of the bile may be found in the general circulation.

Fourth. The liver also aids in the preparation or maturation of young blood-cells in an indirect way. There are certain of the mineral constituents of the disintegrated cells too valuable to be cast away, since they can subserve the duty of entering into the composition of young cells passing toward perfection. As such a substance may be mentioned iron. This view of the action

In what respects are the liver and spleen related? How does the liver promote the maturation of young blood-cells?

of the liver appears also to be sustained by the large number of star-like and corrugated blood-cells occurring in the portal blood of fasting animals, and which are replaced by such as appear to be young and perfect in the blood of the hepatic veins. It is not, however, to be supposed that all the iron is economized in this manner; a considerable portion of it accompanies the pigment as an essential ingredient, and is finally discharged through the intestine.

OF THE DUCTLESS GLANDS.

The salivary and sudoriparous glands discharge their secretion directly through ducts. The liver and kidneys have upon their ducts an additional mechanism, the gall bladder in the one case, and the urinary in the other. These serve as receptacles for storing up the product of action in a temporary manner, and so converting the continuous effect of the gland into a periodical result. In each of these instances we may arrive at conclusions of a certain degree of exactness respecting the functions and use of the gland from a study of the secretion it yields; but there are in the system other glandular organs differing essentially from all the preceding in not being furnished with ducts. These are the spleen, the thymus and thyroid glands, and the supra-renal capsules.

Much diversity of opinion prevails respecting the true nature and action of these bodies. From their structure bearing a resemblance to that of the preceding, with the exception of the absence of a duct, many have thought that, like them, they are really secreting organs. Others have supposed that they have a relation to the nutrition of the system, in giving origin to the development of cells, or that they are connected with the organization of the blood itself; and that such is their duty is perhaps rendered probable by the circumstance that some of them, as the thymus and thyroid, exhibit their utmost development when the body is rapidly growing, and diminish when maturity is reached. That they enjoy a community of action, or that their function can be vicariously discharged by other organs, has been

Is all the iron economized in this manner? Give examples of ductless glands. What are their supposed functions?

clearly established by the result of operations in which one or other of them has been extirpated.

With respect to the spleen, the views of Professor Kolliker are supported by many facts. He supposes that one of the chief functions of that gland is the dissolution of the disorganizing blood-cells preparatory to the action of the liver, in which hæmatin is to be converted into the coloring matter of the bile. In the discussion entered into respecting the origin of the bile, we have come to the conclusion that it is derived from the systemic venous blood, and in the supposition here presented respecting the functions of the spleen there is nothing contradictory, for it is to be remembered that the blood of the spleen is a constituent of the portal circulation. It also appears to be a general opinion that the spleen likewise maintains a mechanical relation to the portal mechanism by serving as a receptacle for any excess of blood, and thus relieving the vessels of pressure, or by acting in like manner when there is any obstruction to the passage of blood through the liver.

As our knowledge of the action of the ordinary glands becomes more accurate, the function of the ductless glands loses much of its peculiarity. As we have already stated, in a certain sense the liver itself may be said to be a ductless gland, for it appears to be one of the constant duties of that organ to prepare sugar from materials in which it did not pre-exist. And this sugar does not escape through the hepatic ducts in company with the bile, but is taken directly into the system through the hepatic veins. But this principle of action is identically what occurs in the case of every ductless gland, and hence it may be inferred that the changes impressed by them on the blood are necessary for the development and nutrition of the system. If the doctrine of Kolliker be correct, the spleen is only an appendix to the liver, and the same duct answers as a common outlet for both.

Dr. Henry Draper investigated the functions of the spleen in 1856 by the aid of microscopic photography. The system he followed was to take a drop of blood

What seems to be the action of the spleen on blood-cells? What mechanical duty does it also discharge? What is in reality the duct of the spleen?

from the splenic vein of an animal, and, at the same time, on an another slip of glass, a drop from an artery in the leg. These were photographed, and the photographs then submitted to a careful inspection and counting. The blood from the leg gave a standard of comparison, and the effect of the spleen was of course fully seen in that issuing from the splenic vein. The conclusion he arrived at was, that "splenic venous blood contains at least double the general average of imperfect blood-discs, and therefore the spleen is an organ for the disintegration of the blood-discs."

CHAPTER XII.

OF EXCRETION.

THE URINE, MILK, AND CUTANEOUS EXCRETIONS.

Of the Kidney: its Structure and Functions.—The Malpighian Circulation.—The Urine.—The Water and Salts exude by Filtration.—The Cells remove unoxidized Bodies.—Manner of Removal of the Liquid from the Malpighian Sac.

Of the Mammary Gland: its Structure.—Colostrum and Milk.—Ingredients of Milk.—Influence of Diet.—Inquiry into the Origin of the Ingredients of the Milk, its Fat, Casein, Salts, Sugar.—Manner of Action of the Gland by Strainage.

Of the Skin.—Structure of its Epiderma and Derma.—Sudoriparous and Sebaceous Glands.—Ingredients of Perspiration.—Exhalation: its Amount.—Causes of the Variable Action of the Skin.—Its Double Action.—Absorption by the Skin.—General Summary of the Cutaneous Functions.

OF THE KIDNEY.

THE non-gaseous products of waste arising from oxidation in the functional activity of the system, the useless materials, saline or otherwise, absorbed in the digestive tract, and carried into the circulation, must be

What is the ratio of imperfect blood-discs found in photographs of the blood of the spleen?

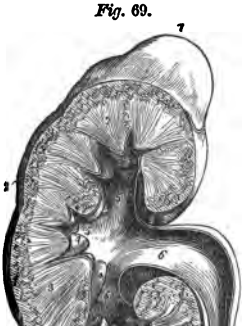
removed. Gaseous substances and vapors may pass away through the lungs, but solid material must be excreted in a state of solution in water. To accomplish this object, a special mechanism, the kidney, is introduced.

In man the kidneys may be described as a pair of dark red ovoid bodies, placed one on each side of the vertebral column, in the lumbar region, the right kidney being a little lower than the left. In the adult the kidney is four or five inches in length, and is enveloped in a mass of fat. Blood is brought from the aorta to supply the organ by the renal or emulgent artery, and is carried back by the emulgent vein into the inferior vena cava. During its passage through the kidney there is removed from the blood a liquid secretion, the urine, which, flowing down a long channel, the ureter, is emptied into the bladder, from which it may be periodically removed.

The supra-renal capsules are bodies of a yellow-red color placed above the kidneys. They are much larger in the fœtus than in the adult, and doubtless have a reference to the peculiar conditions of respiration obtaining at that time.

The substance of the kidney is described as consisting of two portions, the cortical and the medullary or tubular, as seen in *Fig.* 69, in which 1 is the supra-renal capsule; 2, the vascular portion of the kidney; 3 3, tubular portion grouped into cones; 4 4, papillæ projecting into calices; 5 5 5, the three infundibula; 6, the pelvis; 7, the ureter.—(Wilson.) From this it appears that the cortical substance is the external portion, and the tubular is grouped into cones, the base of each cone being outward, and the point toward the pelvis of

Fig. 69.



Section of the kidney.

What class of substances is removed by the kidney? What is the position and anatomy of the kidney? Where are the supra-renal capsules? With what function do they seem to be connected?

the kidney. The cortical substance, however, envelops the cones nearly to their points. It is of a red color, and is the seat of the secreting action. The urine, as it arises, passes along the fine convergent vessels, the uriniferous tubes, and these, coalescing as they approach the points of the cones, give origin to what are termed the ducts of Bellini. From these the secretion passes into the calices, thence into the pelvis, and so along the ureter into the bladder. In the cortical substance there are large numbers of dark points, the Malpighian bodies. Their diameter is about $\frac{1}{100}$ of an inch.

Mr. Bowman has demonstrated that the minute structure of the cortical portion is as follows: The uriniferous tubes, as they approach it, undergo bifurcation in such a way that the branches continually arising have, for the most part, a diameter of about $\frac{1}{150}$ of an inch. As they enter it they are contorted, and at their ends present small capsules or flask-shaped sacs. Each of the capsules is entered by a twig of the renal artery, which at once divides into loop-like branches constituting a tuft, and delivering the blood to a vein originating in the interior of each tuft. These structures are known as the Malpighian corpuscles. The vein and artery pass out of the corpuscles usually at the same point; the vein, however, instead of delivering its blood at once to the renal vein, forms a plexus on the sides of a uriniferous tube. It is supposed that the exudation of the water of the urine takes place in the Malpighian body, and the secretion of the solid portions from the cells covering the uriniferous tubes.

The chief feature of this structure is, therefore, that in a sac formed upon a uriniferous tube, a tuft of capillaries, the walls of which are of extreme tenuity, permits water to escape from the blood supplied by the emulgent artery. The blood, thus concentrated by loss of its water, passes into the veinlets originating in the interior of the tuft; these, converging into a little trunk, less in diameter than the twig of the emulgent artery, escape along with that vessel from the capsule; but, instead of discharging its contents into the renal vein, it

Describe the course followed by the urinary secretion. What is the constitution of the Malpighian bodies? Describe the course of the circulation in the kidney.

ramifies in a plexus on the walls of a uriniferous tube, thus affording a miniature representation of the portal vein, beginning in a capillary system and ending in one. From the plexus the commencing capillaries of the renal veins arise.

Mr. Bowman's explanation of the Malpighian circulation is represented in *Fig.* 70. *a*, branch of renal artery; *af*, afferent vessels; *m m*, Malpighian tufts; *ef ef*, efferent vessels; *p*, their plexus upon the uriniferous tube; *st*, straight tube; *ct*, convoluted tube.

Fig. 70.

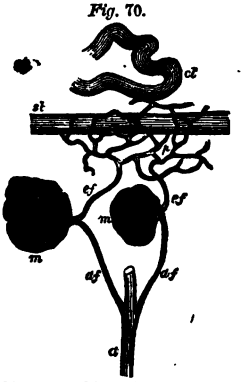


Diagram of Malpighian circulation.

The urine of man is a clear, amber-yellow liquid, the average specific gravity of which may be taken at 1.020, giving an acid reaction when first voided, but gradually becoming alkaline and turbid. Its composition varies greatly with preceding states of the system, and the nature and quantity of the food. It amounts, in the course of a day, to from 20 to 50 ounces; this, however, depending on the quantity of water that has been taken, and on the activity of the skin. Its solid ingredients vary from 20 to 70 parts in 1000 of the urine, the leading substances being urea, uric acid, lactic acid, vesical mucus, epithelial débris, extractive, and salts.

Viewed as a group, the constituents of the urine are evidently the oxidized residues of the system, which, unable, from their not possessing the vaporous or gaseous form, to escape through the lungs, are, from their solubility in water, readily removed by the kidneys. The urea and uric acid are derived from muscular decay; perhaps, of the two, the uric acid first arises, and is subsequently converted into urea; this is not, however, its exclusive source, since the quantity of urea increases by the use of highly nitrogenized food. The mucus and

In what respect does it resemble the portal circulation? Explain the diagram of the Malpighian circulation, *Fig.* 70. What are the properties and quantity of the urine? To what class of substances do its constituents belong? From what sources are the urea and uric acid derived?

epithelial débris are derived from the mucous membrane lining the interior of the urinary apparatus. Of the salts, there are two of unusual interest, the sulphates and phosphates, each having, like the urea, a double origin, the food and tissue decay. Leaving out of consideration that part which has been supplied by the food, we recognize in the sulphates the final disposal of that sulphur which was once secreted by the liver, and subsequently reabsorbed. In the phosphates we recognize the oxidation of the phosphorus of the nervous vesicles during their period of activity. That portion of the solid constituents of the urine due to decay or retrograde metamorphosis is shown when an animal is exclusively fed on sugar.

The composition of urine is not only disturbed by variations in the amount of its normal ingredients, but likewise, in morbid states, by the appearance of unusual ones. Among these may be more particularly mentioned sugar, albumen, blood, bile, pus, fat. The presence of such abnormal ingredients is determined by chemical tests or microscopic observations.

In his inaugural dissertation, entitled, "Is Muscular Motion the Cause of the Production of Urea?" Dr. John C. Draper, by experiments on the urine of persons in different conditions of motion and rest, and by an examination of the diurnal and nocturnal variations in the amount of urea voided, compared with an invariable standard, gives reasons for concluding that the differences in the amount of urea excreted are almost entirely attributable to the influence of the food, an individual in such a state of comparative rest as is observed during treatment for a fractured leg not excreting by any means so much less urea as might have been anticipated when compared with another individual who walked thirteen miles at the rate of four and a half miles an hour.

But, on examining the influence of food, it appears to be well marked. The greatest amount of urea is excreted within a few hours after dinner. Another maxi-

From what source is the mucus derived? From what the sulphates and phosphates? What unusual substances may occur in urine? What reasons are there for supposing that urea is mainly due to the ingestion of food?

mum also occurs just after breakfast; but during the eight night hours far less is excreted than during the same period in the afternoon.

The ingestion of food thus exercising so rapid and marked an influence on the quantity of urea, he refers to it as the cause of the increased excretion of that substance during the course of the day rather than to the increased motion of exercise then indulged in; and in view of this conclusion, it becomes probable that the nitrogen of the wasting muscular tissues escapes, not under the form of urea through the kidneys, but through the skin, or perhaps even as free nitrogen from the lungs.

Of medicaments and other unusual substances introduced into the organism, those that are soluble in water, and have little affinity for the constituent matters of the body, are removed in the urine. In this list are found a great number of salts escaping in this manner without undergoing any change; such, for example, as carbonate of potash, nitrate of potash, bromide of sodium. Other substances undergo change previously to their elimination, as, for instance, the alkaline sulphides, which become oxidized, and are then finally removed as alkaline sulphates.

The anatomical construction of the Malpighian bodies has led physiologists to infer that there are two distinct stages in the secretion of urine. These have already been pointed out in the remark that the Malpighian bodies separate water from the blood, but that the solid ingredients are secreted from the delicate plexus of vessels covering the walls of the urinary tubes. Before accepting this opinion, we may, however, observe, that the chief solid constituents of the urine, as urea, uric acid, sulphates, and phosphates, pre-exist in the blood, and are all soluble in water. It is not to be supposed that the water oozing through the delicate walls of the Malpighian tufts should leave such substances behind it. That the loss of water actually takes place in the tuft circulation appears to be proved by the fact that the vessel emerging from the tuft is less than the one enter-

What saline substances are removed from the system by the kidneys? What two stages are there in the secretion of urine? How is it known that water is lost in the tuft circulation?

ing it; the volume of blood is less by the amount of abstracted water.

We must, moreover, take care that we are not deceived by a name. The vessel emerging from the tufts may be conveniently enough called a *vein*, but is there any proof that such is its physiological attitude? There is no reason to believe that the blood has lost its arterial character while it has been in the tuft. At the most, it can only have lost the elements of urine. It is not until it is distributed in the plexus on the walls of the uriniferous tubes that it really gains the venous character, and then through nourishing those vessels, and particularly the cells of their interior.

These considerations therefore lead me to the suggestion that the inorganic bodies, as urea, uric acid, sulphates, and phosphates, pass out with the water in which they are dissolved while the blood is yet circulating in the Malpighian tuft. The loss of velocity in the current by the arterial twig breaking up into so many vessels must, as Mr. Bowman states, greatly favor this transudation, as does also the pressure that must arise from the blood having to pass through a narrow channel of exit, and still more through another capillary system just beyond. It was arterial blood that entered the tuft, and it is arterial blood that emerges, to be then directed upon the walls of the uriniferous tubes.

And now the question may arise, What is the object of this second capillary circulation? Though the statement is often made that the constituents of the urine are the results of oxidation, it is very far from being strictly true. The analysis of urine shows that a very large proportion of them, classed as extractive, are really combustible bodies, and not far advanced in their retrograde metamorphosis. They retain still, as it were, the traces of organization; they belong rather to the hydrocarbon family than to the nitrogenized. It may be that, for the removal of these, cell action is necessary.

Whatever importance may be attached to such a suggestion, it is very clear that, notwithstanding the extreme thinness of the walls of the tuft vessels, the relaxation in the speed of the blood current through them,

Why must saline substances accompany it? What is the object of this second capillary circulation?

and the pressure brought to bear upon them, that water could not be separated by oozing through them unless there was an additional provision. The sac into which the exudation is to take place is already full, and it may be questioned whether ciliary motion in the uriniferous tubes would exert a sufficient exhaustion to relieve the interior of the capsule from pressure; but the introduction of a liquid of a different nature into the uriniferous tube may call at once into operation the principle acting in the capillary circulation of the blood, and thus the contents of the Malpighian sac are drawn forward into the uriniferous tube, just in the same manner that water is drawn from the inside of a bladder through the pores thereof by alcohol on the outside.

THE MAMMARY GLANDS.

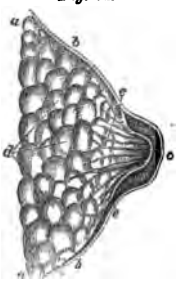
The mammary glands are situated on various portions of the abdominal and thoracic surfaces of animals of the class mammalia. In the higher members of this class they present the appearance of racemose glands, rudimentary in the males, but well developed in the adult females, especially after parturition. They separate from the blood the white secretion, milk.

In different cases the number of mammæ differs. In the human species there are but two, placed upon the thoracic surface, and from their position favoring the care and nursing of the child. Among other animals the number seems to have a relation to the number of young brought forth at a birth, there usually being a pair for each one. Many exceptions to this rule, however, occur.

The mammary gland corresponds in anatomical structure to the parotid and pancreas. It consists of 15 or 20 lobes, each from ½ to 1 inch in width; these are composed of lobules, and these, again, of cæcal vesicles. The excretory ducts are lined with tesselated epithelium. The ducts converge toward the nipple, opening upon it by 10 or 15 apertures, and in their course dilating into ampullæ, of small capacity in women, but in the cow capable of holding a quart.

What is the mode of removal of the liquid from the Malpighian sac? Describe the mammary gland? What number is there usually of them? What is its anatomical construction?

Fig. 71.

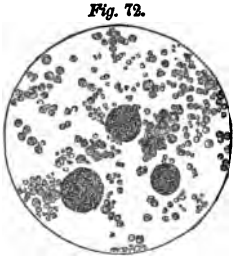


Section of the human mammary gland.

Fig. 71, vertical section of the human mammary gland: *a a*, its pectoral surface; *b b*, skin on surface of the gland; *c*, skin of nipple; *d*, lobules and lobes of gland; *e*, lactiferous tubes passing from the lobules to the nipple.

Milk globules are minute particles, varying in their diameter from the $\frac{1}{3000}$ to the $\frac{1}{13000}$ of an inch. They consist of oily material inclosed in an envelope, as is shown by the fact that, though they will resist for a short time the action of sulphuric ether, they are finally dissolved by that substance. Besides these milk globules, there are other exceedingly minute fat particles present. The milk which is first secreted contains corpuscles of considerable size, and of a granulated appearance, as seen in the photograph, *Fig.* 72. They are called colostrum corpuscles. They are soluble in ether, and therefore contain fat. There is reason to suppose that all the fat globules of the milk are inclosed in cyst-like pellicles of casein.

Fig. 72.



Milk with colostral corpuscles.

In the chapter on food (Chapter II.), a general description of the character and constitution of milk has been given, together with its physiological relations in nutrition. It may now be added that fresh milk presents an alkaline reaction. Left to itself, and the more quickly the warmer the air, milk turns sour through the production of lactic acid, the casein undergoing coagulation. That the oil globules just spoken of are coated with a film of a coagulated protein body appears from the circumstance that it may be dissolved by acetic acid, and the included butter is then set free.

The composition of milk varies with many circumstances. Thus, among cows, it is well known that there are certain breeds yielding a milk in which butter pre-

Describe the section, *Fig.* 71. What are milk globules? What is colostrum? What are the properties of milk?

dominates; in others, a milk containing an excess of casein. It is in reference to this that such are, among agricultural people, often described as good butter cows, or good cheese cows, as the case may be. Such variations are likewise often popularly referred to peculiarities in the color of these animals; and, indeed, there is a general impression of the same kind as respects the milk of women, that that of fair women is inferior to that of brunettes.

As would be expected, the constitution of the milk varies greatly with the diet. Simon found that in the case of a very poor woman, who had been almost deprived of the necessaries of life, the quantity of solid material was only 8.6 per cent. On giving her a nutritious meat diet it rose to 11.9 per cent. Being again reduced, by circumstances, to the utmost destitution, the solid residue sank to 9.8 per cent.; and on once more being supplied with nutritious meat diet, the percentage rose to 12.6.

The diurnal quantity of milk yielded by the human female has been estimated at from 32 to 64 ounces. This estimate is made by determining the weight of the infant before and after suckling. Although a certain proportion is present in the gland, the secretion appears to take place for the most part with great rapidity. On the application of the infant the blood flows suddenly, and the milk pours into the ducts, constituting what is termed the draft.

We now enter on a consideration of the function of the mammary gland, with a view of determining whether it acts in virtue of its special construction, whether it fabricates in itself, by the agency of cells, the proximate constituents of milk, or whether it merely strains them from the blood in which they pre-exist.

Due weight should here be given to the fact that, unlike the excretions of the lungs, the kidneys, or even the liver, the milk contains a large percentage of histogenetic or formative bodies. Its casein can not be considered as in the career of retrograde transformation,

In what respect does its composition vary? What effect have variations of diet on milk? What is its diurnal quantity? How is it known that the structure of the mammary gland is not essential to the secretion of milk?

since in the body of the infant it is presently changed into albumen. Such a fact might even lead us to suspect that we should detect some essential structural and functional differences between the mammæ and other glands.

The influence of special structure is, however, disposed of by the numerous well-authenticated cases now on record, in which portions of the skin, or the stomach, the navel, intestines, the axilla, and glands in the groin have assumed a vicarious action, and secreted milk; and though it has been said of the latter instance that it may be nothing more than an obscure manifestation of an attempt in the human species at a repetition of the mammary gland in a region near which it is normally present in the lower mammals, such a remark has no application in the other cases. We may therefore infer that the proximate constituents of the milk are not manufactured by reason of any special structure of the gland secreting them, since other structures can assume a vicarious action.

This therefore narrows our inquiry down to the point, Does the mammary gland merely filter off from the blood substances already existing in it, or, those substances not so pre-existing, are they made in this organ by cells?

Of the proximate elements of milk, many, such as the entire group of its salts, are acknowledged on all hands to pre-exist in the blood; and these, constituting about $\frac{1}{15}$ of its solid ingredients, must be admitted to pass into the secretion by strainage only. Of the other solid ingredients, the fat, constituting about one fourth, also exists in the blood, being derived by lacteal absorption from the food.

Do milk-giving animals, then, find in their ordinary diet a sufficient quantity of oleaginous material to supply the drain established through the mammary gland, and the calorifacient demand, supposing none to be made in the system? The researches of Dumas have definitely settled this question. Of these the following is an abridgment:

What instances of vicarious action have been recorded? Do the salts of milk pre-exist in blood? Do the hydrocarbons exist in food?

Fat in Articles of Forage.

Indian Corn	8.75	per cent.
Rice	1.00	" "
Oats	3.30	" "
Rye	1.75	" "
Wheat	2.10	" "
Dry Hay	2.00	" "
Clover in flower	4.00	" "
Wheat Straw	3.20	" "
Oat Straw	5.10	" "
Beet-root	0.05	" "
Potatoes	0.08	" "

A cow in good condition, eating 100 pounds of dry hay, will furnish 21 quarts of milk, from which there can be obtained 1½ pound of butter. If this butter was obtained exclusively from the food, and none made in the system, we ought to find in the 100 pounds of dry hay 1½ pound of fatty matter; but sulphuric ether can remove from such hay 2 pounds, and in several specimens of clover cut in flower, M. Boussingault found the proportion as high as 4 per cent. We may therefore affirm, relying on the universal experience of farmers, that the hay eaten by a milch cow contains more fat matter than the milk she yields.

There are many facts showing that the identical fat occurring in the food is actually delivered by the mammary gland with many of its qualities unchanged. Thus, if by chance cows eat the tender shoots of pine-trees, or wild onions, or other strong-smelling herbs, the milk is at once contaminated with the special flavor of their oils. The same, too, takes place when turnips are introduced in their diet. If half the allowance of hay for a cow is replaced by an equivalent quantity of linseed-cake, rich in oil, the cow maintains herself in good condition, but the milk produces a butter more than usually soft, and tainted with a peculiar flavor derived from the linseed oil.

To the preceding facts it is unnecessary to add any observations in relation to the carnivorous animals, which obviously find in their prey large quantities of

Mention the percentage of fat in some of the leading articles of forage. What general conclusion is come to in the case of the milch cow? How is it known that the identical fat of the food occurs in the milk?

fat. In the chapter on calorifacient digestion, and in that on the functions of the liver, the evidence was presented both as regards the reception of oily material from the food, and likewise its fabrication in the system. From these sources conjointly it may therefore be plainly seen that fats of various kinds must always exist in the blood. A simple arithmetical computation, founded on the data furnished by the tables of the constitution of blood and of milk respectively, will show that there is at any moment a sufficient supply of fatty matters in the blood to furnish two thirds of the diurnal amount of milk. It does not seem, therefore, philosophical, under the circumstances, to impute to the mammary gland a power of forming butter.

Next of the casein. There has been much controversy among chemists respecting the existence of casein as a normal ingredient in the blood. Theoretically there does not appear any solid reason for denying that it may be one of those constituents, considering its analogy of constitution to albumen. The evidence is much more distinct and positive in the case of puerperal blood, and is greatly strengthened by the recognized tendency to the occurrence of kiestine in the urine during gestation.

The occurrence of casein under the form of kiestine in the urine, in quantity increasing as gestation advances, indicates therefore that the system is assuming a propensity for the generation of this substance from its albuminoid compounds; and since, in cases of starvation, the percentage of casein in the milk does not seem to be materially affected, we are to attribute its immediate source to the system rather than to the food. In this respect it differs from the oily constituent, butter, the percentage amount of which is instantly affected by variations in the nature and quantity of the food. It would seem, indeed, that, from the same plastic ingredient, albumen, the soft tissues of both mother and infant are fabricated, with this difference, that in the latter case the temporary condition of casein is intermediately assumed. There is reason to conclude that casein

What quantity of fatty matters exist in the blood? What reasons are there for supposing that casein exists in the blood? Under what circumstances does kiestine occur?

is directly derived from the system, which can manufacture it at a rate of about 30 grains per hour, this being about one half the quantity of fibrin generated in the same period of time for the support of the muscular tissues. Chemically, the transition from albumen to casein is not to be regarded either as an ascending or declining metamorphosis, but only as the temporary assumption of a state of passage onward to the condition of fibrin.

The remarks just made respecting the origin of casein are applicable to the saccharine constituent of the milk, the origin of which is not to be attributed so much to the food directly as to the system; for, in starvation, sugar, like casein, still continues to form to nearly the normal amount. I think it is probable that its production is due to the liver, and is, in reality, nothing more than an indication of the continued action of that gland, one of the prime functions of which is the generation of saccharine compounds.

From the data now before us respecting the origin of the different constituents of the milk, casein, butter, sugar, and salts, we are able to come to a definite conclusion regarding the physiological action of the mammary gland. I have entered on this disquisition from the important bearing the decision we arrive at has upon the whole theory of secretion; for if there be a gland in the body in which we should expect to find proofs of formative power, through the agency of cell life or otherwise, in giving rise to products that do not pre-exist in the blood, it is certainly the mammary. But now, as it appears that all the constituents its secretion contains are found in the blood, we can scarcely suppose that the gland itself does more than merely strain them out; of course, in common with all such structures, it possesses what might aptly be termed an elective filtrating power; thus it permits the exudation of the iodide of potassium from the blood, but refuses a passage to the ferrocyanide. And, finally, the conclusion we thus come to recalls the remark heretofore made, that the more thor-

What quantity of casein can the system produce in an hour? What is the origin of the sugar of milk? To what conclusion may we come respecting the action of the mammary gland? How does this bear on the general theory of secretion?

oughly we study the secretions delivered by the various glands, and the more perfectly we identify the sources from which their constituent ingredients have been derived, the more we should be disposed to impute glandular action to the physical process of elective filtration, and the less to the agency of cell life.

OF THE SKIN.

The skin is composed of two layers, the epidermis or cuticle, and the derma or cutis. It contains two systems of glands, one for the removal of water, and another for that of oily substances. It also presents subsidiary parts or appendages, such as the nails and hair.

The epidermis, or exterior portion of the skin, originates from the cutis. It has a different thickness in different parts; the contrast, in this respect, being very well shown upon the soles of the feet and the eyelids. In this respect its use is mechanical. It serves as a protective covering to the parts it envelops, being thick where pressure and hard usage have to be provided for, and thinner where there is a necessity for motion. It consists of an aggregation of nucleated particles adhering together, the deepest being granules, the intermediate more perfect cells, which gradually become flattened scales as they are examined nearer the surface. They undergo constant exuviation, and are as constantly replaced from beneath, the superficial ones becoming dry and horny, thus furnishing a resisting tegument.

At one time it was supposed that the rete mucosum, or layer of Malpighi, which is the lowest portion of the cuticle, and therefore resting on the cutis, is a distinct structure. It is, however, merely the most recently-formed portion of the cuticle. The netted appearance it presents originates in the eminences of the papillary structure below. Many of its constituent particles contain coloring matter, especially in the dark races. The pigment seems to be produced by the agency of the sunlight and continued high temperature, though it disappears gradually as the cells containing it approach the surface. It yields a very large percentage of carbon.

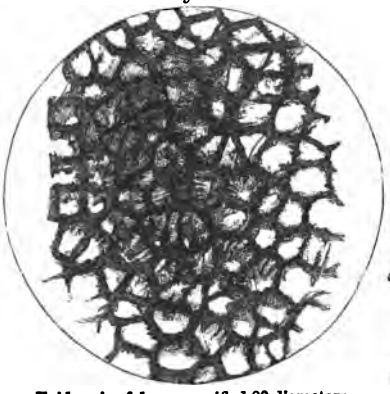
Of how many layers is the skin composed? What is the structure and use of the epidermis? What is the rete mucosum and its origin?

Beneath the epidermis is the derma or true skin. It is composed of fibrous tissue, which also serves to connect it with the parts beneath, blood-vessels, lymphatics, and nerves. In its areolar tissue both the white and yellow fibrous elements are found, the proportion of each varying according to the mechanical function the part has to discharge, the yellow predominating where elasticity is required, and the white where a resistance to pressure. The derma also contains organic muscular fibres, to which its property of corrugation, as in cutis anserina, is due. On different parts it is of different thickness, being thinnest where motion has to be provided for. A deposit of fatty material, lodged beneath, gives it a yielding support. Its outer surface presents a papillary structure, the instrument of touch. This is more perfectly developed on the inner surface of the palm of the hand and fingers. The furrowed aspect of the cutis arises from this. A farther consideration of the mechanism and functions of the papillæ is deferred to the description of the sense of touch.

The photographic engraving, *Fig.* 73, represents a thin section of the epidermis of the foot of the dog.

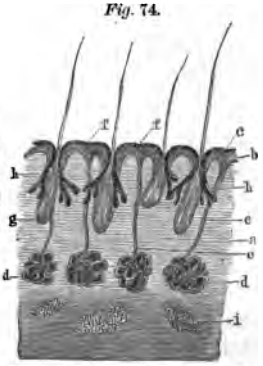
The general method of arrangement of the constituent portions of the skin may be gathered from the perpen-

Fig. 73.



Epidermis of dog, magnified 20 diameters.

Fig. 74.



Perpendicular section of skin of ear, magnified 10 diameters.

Of what is the true skin composed? To what is its occasional corrugation due? Where is the papillary structure most developed?

dicular section of that of the external auditory meatus in *Fig.* 74 (page 205), *a*, the derma; *b*, rete mucosum; *c*, horny layer of epiderma; *d*, coil of ceruminous glands; *e*, their excretory ducts; *f*, their apertures; *g*, hair-sacs; *h*, sebaceous glands; *i*, masses of fat.

The SUDORIPAROUS GLANDS originate in depressions of the cutis or tissues beneath, occurring in some parts, as in the axilla, more numerously than in others. They consist of a tube wound on itself, and sometimes dividing in convoluted branches. The knot thus arising is contained in a cell, the wall of which is copiously supplied with blood-vessels: the duct passes through the superjacent tissues. The tube is formed of a cylinder of basement membrane lined with epithelium. The basement membrane may be considered to be derived from the outer surface of the papillæ, and the epithelium is an external projection of the cuticle. The duct, on its passage outward, loses its basement membrane as it escapes between the papillæ; and it has a spiral or helical aspect, an arrangement probably intended to keep the calibre open. It is estimated that the number of sudoriparous glands is about seven millions, and the total length of their tubing about 28 miles.

Fig. 75.



Sudoriparous gland, magnified 20 diameters.

Fig. 75 is a sudoriparous gland from the palm of the hand: *a a*, knot of tubes with two excretory ducts, *b b*, uniting into a helical canal, which perforates the epidermis at *c*, and opens on its surface at *d*: the gland is imbedded in fat vesicles at *e e e e*.

The SEBACEOUS GLANDS are distributed in different abundance in various parts, their office being to lubricate the hair, to keep the skin in a flexible condition, and avoid the inconveniences of friction. Their ducts open either into the hair follicles or upon the cuticular surface; the gland consisting of basement mem-

Describe the section, *Fig.* 74. Describe the sudoriparous glands. What is the length of their tubing? Describe *Fig.* 75. What is the office of the sebaceous glands?

brane lined with epithelium, the cells of which, as they reach maturity, become filled with a sebaceous or oily material. The ear glands of this class secrete a waxy matter.

Such being the construction of the skin, we have next to speak of its action. It discharges a double function: 1st, as an excreting, and 2d, as an absorbing organ. In this respect it has an analogy with the mucous membrane, which, indeed, is a reflection or continuation of it.

The skin permits water, saline and fatty substances, to escape from it in quantities differing on different portions of its surface, the nature of the secretions varying to meet local requirements. In the examination we are now entering upon, we shall speak of these substances and their proportions in a general way, overlooking, for the time, the particular variations. Yet that such variations exist is clear on the most superficial observation. The sweat of the feet differs from that of the general surface, as, again, does that of the arm-pits.

It has been usual to distinguish the watery transudation into two portions, that escaping from the perspiratory ducts, and that passing through the surface of the cuticle. It has even been said that the true glandular secretion passing from the ducts is not more than one sixth of the total cutaneous exudation; but this, I believe, is altogether erroneous. When we recall the impermeable nature of the horny and dried scales constituting the outer portion of the cuticle, and that these are constantly coated over with an oily varnish issuing from the sebaceous glands, we may infer that the cutaneous surface between the mouths of the perspiratory ducts is constructed rather for the hinderance of evaporation than for its promotion; and though the oily matter with which the skin is thus imbued is justly regarded as having for one of its functions the prevention of injury from the admission of external moisture, it must be equally effectual in stopping the escape of water from within. The tardy manner in which water thus escapes is illustrated by the operation of blisters.

What functions does the skin discharge? What substances escape with the water of perspiration? In what manner is the water removed?

Under the form of steam, water continually escapes from the skin. It also, on certain occasions, issues in the liquid state as drops of sweat. To its escape under the form of steam the designation of exhalation or insensible perspiration is given; but if under the form of sweat, that of sensible perspiration.

Of Exhalation.—On condensing the vapors arising from the skin, they are found to consist of water containing a little acetate of ammonia. With the water likewise escapes carbonic acid gas. From the experiments of Valentin, the average of loss of water through the skin is two pounds and nearly half an ounce a day. Seguin's experiments would make it two pounds and three quarters. It has been shown in Chapter X. that the action of the skin is partly meteorological: the amount of water passing through it depends on the dew-point, the atmospheric temperature, the conductibility and perviousness of the clothing. Whatever physical circumstances promote surface evaporation correspondingly promote the action of the skin. Moreover, this membrane acts vicariously with the kidneys, and this not only as regards the water, but also as regards the solid matter, a large amount of which is thrown off in the course of the day.

Of Perspiration.—When the atmospheric temperature is high, and more particularly if muscular exertion be resorted to, the quantity of water issuing from the perspiratory ducts is so great that it can not be evaporated. It then exudes as drops of sweat, which become mingled with the oily secretion prepared by the sebaceous glands. From this commingling it is scarcely possible to obtain the sweat, in an uncontaminated condition, suitable for analysis, or even to exclude the detritus of the cuticle itself. In a thousand parts of sweat there are from five to twelve and a half parts of solid material.

I have spoken of the double action of the kidney, its mechanism for removing saline solutions, and also that for combustible material. The functions of the skin are

What is meant by sensible and insensible perspiration respectively? What estimates have been made of the quantity of water thus removed? Why does the skin act in a variable manner? What quantity of solid material is found in perspiration?

similar. It is not a mere analogy that exists between the action of these organs; the occurrence of urea and of the salt substances, in both secretions, is a fact of the utmost significance. I believe that the sudoriparous glands are the counterparts of the Malpighian bodies, and the sebaceous glands, in their function, are the counterparts of the uriniferous tubes.

Besides exercising the functions of exhalation and perspiration, numerous facts demonstrate that the skin exerts an absorbent action. The endermic application of remedial agents establishes this in a satisfactory manner. That water can find access in this way is shown by the assuaging of the thirst on taking a bath; nor is the amount insignificant, since it may give rise to a considerable increase of weight. Gaseous substances also find entrance through the skin. If the hand be put into a bell-jar containing oxygen, nitrogen, or carbonic acid at the pneumatic trough, absorption of those gases ensues. Probably it is a standard function of the skin to permit a partial arterialization of the blood, atmospheric oxygen being exchanged for carbonic acid through it, an action the residual trace of the community of function between the skin and mucous membrane. In the case of some animals this cutaneous respiration is well marked.

Recapitulating now the more important actions of the skin, the following statement may be made: It regulates, to a certain extent, the amount of water in the system, disposing of it, as the case may be, either as sensible or insensible transpiration. The water doubtless maintains its liquid condition until it presents itself at the mouths of the sudoriparous ducts, moistening the general surface of the skin, and then being evaporated; or, if the supply be greater than can be thus removed, it accumulates as drops of sweat. There appears to be no substantial reason for believing that any portion of water transudes directly through the structure of the cuticle, since the scales composing it are of an impervious and almost horny nature, and their interspaces are fortified against any such leakage by the oily exudations

What is meant by the double action of the skin? What analogy does it bear to the action of the kidney? How may it be shown that the skin absorbs water? How may it be shown that it absorbs gases? Give a summary of the action of the skin.

of the sebaceous glands. With the water thus presenting on the surface are many compounds which are also constituents of the urinary secretion. Among these, urea may be particularly pointed out, thus indicating a similarity of instrumental action between this organ and the kidneys, and this is farther substantiated by both containing provisions for the elimination and escape of the hydrocarbons; but besides these direct functions there are other very important collateral agencies the skin exerts, and particularly as a regulator of temperature. In this respect the action is, to a certain extent, meteorological. But this has been previously treated of so much in detail that it is unnecessary to resume the consideration of it now.

CHAPTER XIII.

OF THE NERVOUS SYSTEM.

Divisions of the Nervous System.—Cerebro-spinal and Sympathetic.—Fibrous and Vesicular.
Structure and Functions of Nerve Fibres.—Centripetal and Centrifugal.—Rate of Conductibility.
Anatomical Examination of the Structure and Functions of Nerve Vesicles.—They diffuse Influences, are Magazines of Force.—Element of Time introduced by Registering Ganglia.—Oxidation necessary to Nerve Activity.—Necessity of Repair and Rest.—Electrical Examination of the Functions of Vesicles.—Anatomical and Electrical Examinations agree.
Vestiges of Impressions and their Interpretation.—Finite Nature of Knowledge.—Mental Emotions.

THE nervous system is regarded as consisting of two portions, the cerebro-spinal and sympathetic. The former is composed of the spinal cord, the brain, the nerves proceeding from them, and their ganglia; the sympathetic is composed of a series of ganglia, united by intercommunicating threads on each side of the vertebral column, and supplying branches to the coats of the

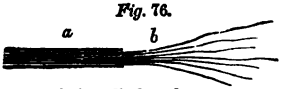
Into what portions is the nervous system divided?

blood-vessels and viscera of the great cavities. Both portions contain two kinds of structure, a fibrous and a vesicular.

Of the FIBROUS there are two varieties, one belonging to the cerebro-spinal, and the other to the sympathetic. The former may be described as a delicate membranous tube, containing a semi-fluid material, and presenting under the microscope a pellucid glassy appearance when examined in the recent state; a spontaneous separation or partition, however, soon ensues, a white material or medulla appearing immediately within the membranous tube, and affording a contrast to the portions toward the centre or axis. In this state the nerve-tube presents the appearance of parallel lines toward its periphery, the outer one corresponding to the membranous sheath, and the inner to the internal limit of the coagulated material. In this condition the tube is very prone to assume a beaded appearance, either by the influence of pressure, or spontaneously. Names have been given to distinguish these parts from each other; the central grayish portion is called the axis cylinder or axis band, since it may be of a flattened shape; and the material surrounding it, intervening between it and the membranous investment, is designated the medulla or white substance of Schwann. There can be no doubt that the membranous tube, the white substance, and the axis cylinder discharge different physiological functions. In chemical composition they also differ: the tube is a nitrogenized structure, the white substance oleaginous, and the axis cylinder is supposed to be nitrogenized also. In the first development, the axis cylinder is first formed, and the white substance then cast round it.

If a portion of a nerve, *a*, *Fig.* 76, be placed in concentrated acetic acid, the axis cylinder of its included tubes will, in the course of a day or two, be seen protruding in a brush-like form, as at *b*, the effect being very well shown when the nerve is suffi-

Fig. 76.



Axis cylinder of nerves.

What structures do both contain? How many varieties of the fibrous are there? Describe the cerebro-spinal. What is the appearance of such a nerve-tube after death? Where is the white substance of Schwann? What effect is represented in *Fig.* 76?

ciently slender to be subsequently examined by the microscope.

Of fibres, arranged parallel to each other in bundles, the bundles united by fibro-cellular tissue, nerves are composed, the tissue not only accomplishing that mechanical object, but also affording a nidus for blood-vessels, running in a course parallel to the nerve fibres. Though we have spoken of those fibres as cylinders, they, in reality, approach more nearly to the figure of acute cones, since, though their diameter is from the $\frac{1}{2000}$ to the $\frac{1}{3000}$ of an inch in the nerve trunks, they diminish to the $\frac{1}{10000}$ or the $\frac{1}{14000}$ of an inch as they reach the nerve centres, and, in the same manner, their diameter becomes less as they branch off in their peripheral distribution.

The sympathetic fibres differ from the preceding in appearance. Being of a yellowish-gray color, and only about half as large, they do not show the separation into an axis cylinder and white investment after death, as is the case with cerebro-spinal fibres; they may therefore be regarded as being more homogeneous in their construction, or possessing a constitution like that of the other kind of fibres when they undergo diminution and approach their central or peripheral termination. Even in the cerebro-spinal fibres the quantity of white substance present is very variable; the retina, the olfactory organ, and the Pacinian corpuscles furnish instances of its absence. The sympathetic, gray, or gelatinous fibres, as they are indifferently called, contain many nucleated corpuscles, rendered very distinct by the action of acetic acid.

Nerve fibres terminate in various ways. Their ends may thin out and become free, or they may form a loop, and so return back in their course. Each nerve runs in an unbroken line from its origin to its termination, but between the adjacent ones intercommunication is established by the formation of plexuses. On the other hand, as the fibres are preparing to enter nervous centres, the membranous tube dilates so as to receive a nerve vesi-

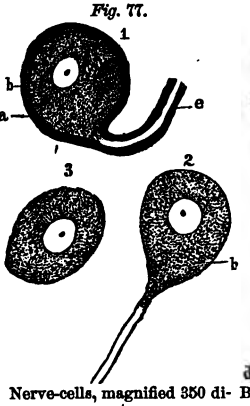
Why may these fibres be spoken of as cones? Describe the sympathetic fibres. What relation do they bear to the cerebro-spinal? In what modes do nerve fibres terminate? In what manner are they attached to the vesicles?

cle, with which the diaphanous axis cylinder is thus brought in contact. Where corpuscles are received into the membranous sheath, it is not always certain but that the fibre has some other termination beyond.

The VESICULAR nervous substance is composed of nucleated cells, containing a granular substance, with which there are intermixed, especially near the nuclei, pigment granules. These granules, however, are sometimes absent, as in the vertebrata. The nucleus of each ganglionic vesicle often presents a nucleolus; the diameter of the vesicle varies from $\frac{1}{300}$ to $\frac{1}{1250}$ of an inch. These vesicles are found in the nerve centres, their coloring material communicating to those parts the peculiar tint they display. In shape they vary very much, some being spherical, some ovoid, and others caudate, exhibiting processes filled with granules, or which, becoming eventually transparent, communicate with similar processes from other cells, or are continuous with the axis cylinders of the nerve-tubes. The axis cylinder is perhaps a continuation of the nucleus of the cell. The ganglion vesicles, as they are termed, are characterized by containing a large amount of phosphorized oil, and it is probable that the oxidation of this material is a condition of their functional activity.

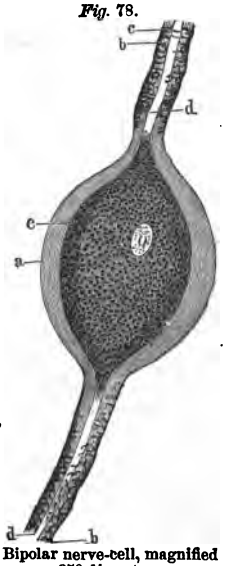
Fig. 77, ganglion globules (nerve-cells), from the Gasserian ganglion of the cat. 1. Cell, with short pale process, showing the origin

Fig. 77.



Nerve-cells, magnified 350 diameters.

Fig. 78.



Bipolar nerve-cell, magnified 350 diameters.

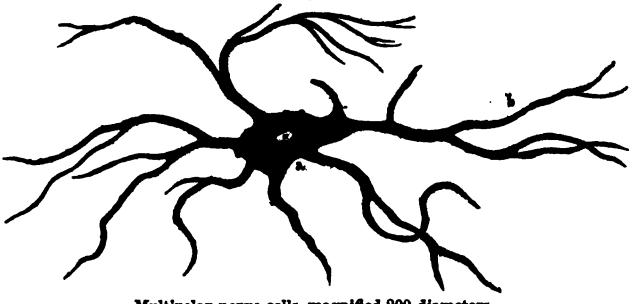
Describe the composition of vesicular substance. What does *Fig.* 77 indicate?

of a fibre; *a*, sheath of the cell and nerve-tube, containing nuclei; *b*, cell membrane of the nerve-cell. 2. Cell, with the origin of a fibre without sheath; *b*, cell membrane of the nerve-cell. 3. Nerve-cell, deprived, in the preparation of it, of its membrane and external sheath.

Fig. 78 (page 213), bipolar nerve-cell of the pike, continued at each end into nerve-tubes. *a*, sheath of the nerve-cell; *b*, sheath of the nerve; *c*, medulla; *d*, axis cylinder continuous with the contents of the nerve-cell, *e*, which have shrunk away from the sheath after action by arsenious acid.

Fig. 79, caudate nerve vesicle of the multiple kind: *a*, the nucleated vesicle; *b*, its processes. These prob-

Fig. 79.



Multipolar nerve-cells, magnified 200 diameters.

ably are continuous with the axis cylinders of the nerves, in connection with the vesicle.

FUNCTIONS OF NERVE FIBRES.

That the function of nerve fibres is to conduct impressions, is proved by many different facts. On putting a ligature round a nerve, or cutting it across, it no longer transmits the usual influences. A more critical examination shows that impressions made on the external extremities of a nerve are conveyed by it to the centres, and the influences originating in the nervous centres are conducted along such trunks to the parts to which they are distributed. This double duty therefore implies

What are unipolar, bipolar, caudate vesicles? What is the function of nerve fibres? What is the effect of a ligature or section of a nerve?

that there are two classes of fibres, the centripetal and centrifugal, though thus far no structural difference between them has been detected. They can not of themselves either originate impressions or motions, these in every instance arising from external or central agency. The centrifugal fibres, when cut across, may show no effect if the part still remaining attached to the nerve centre is irritated; but if the other part connected with the periphery be pressed upon or pinched, muscular contraction, that is, motion, results. If centripetal fibres be examined in like manner, the part connected with the periphery being irritated, no result arises; but if the part connected with the centre be irritated, sensations, general or special, as the case may be, are perceived. These several effects ensue when the motor or sensory nerve is intact; for, on irritating the one or the other, motion or sensation, as the case may be, is produced. If the whole trunk of a centripetal nerve be irritated, the mind refers the sensation to all those parts to which the branches of that nerve are distributed; if a part only, then the sensation is limited to those portions to which the fibrils of that part go; but, besides this, the mind also recognizes the particular spot upon the trunk to which the irritation has been applied. In like manner, when the entire trunk of a centrifugal nerve is irritated, all the muscles it supplies contract; or, if only a part, then those muscles supplied from that part. From the anatomical fact that a nerve fibre does not anastomose with its neighbors, the influences it conveys are transmitted along it without any lateral diffusion, and every fibre discharges one duty, and one alone. The centripetal can never assume the function of the centrifugal; and in the case of nerves of special sense, there is the same restriction: the optic nerve can not transmit the impressions of sounds, nor the auditory the vibrations of light; the nerves of common sensation are affected neither by one or the other, but they are by variations of temperature. The velocity with which these influences pass along nerve fibres is indefinitely less than that with which electricity moves in a metal conductor. Thus

How many classes of fibres are there? What is the effect of irritating a sensory or a motor fibre? Do nerve fibres ever discharge more than one function?

far, however, no satisfactory measure of it has been obtained. The experiments of Helmholtz give, for the rate of propagation, from 83 to 88 feet per second in the frog, and in man 200 feet, the velocity rising with the mean animal heat. It can not be denied that there is a general resemblance between the manner in which a nervous fibril transmits its influences and that in which a conducting medium conveys an electric current, though the velocity may be very different. There is a resemblance between the arrangement of the axis cylinder surrounded by its white substance and membranous tube, and that of a metalline wire wrapped round with silk, or other non-conducting material in many electrical arrangements. An electric current artificially transmitted along a nerve trunk will, as the nature of that trunk may be, give rise to muscular contraction, or produce general or special sensations, or originate reflex action. For these reasons, it has long been supposed, by many physiologists, that the influence passing along nervous fibres is analogous to electricity, if it be not identical therewith; but all attempts to prove the existence of an electric current, either in the centripetal or centrifugal fibres, have thus far been abortive.

FUNCTION OF NERVE-CELLS.

The nervous fibres having for their duty the conduction of external impressions and the transmission of nervous influences, the nerve-cells or vesicles are for the reception of those impressions and the origination of those influences. The nerve centres or ganglia are made up of vesicles, granules, and nerve-tubes conjointly.

For the explanation of the function of the nerve centres, it is essentially necessary that we should have clear views of the function of the nerve vesicles. It has appeared to me that their duty is manifested by their anatomical relations. The influence, whatever it may be, passing along a nervous cord, is completely isolated therein, and never leaves the fibril in which it is passing from its origin to its termination. It is isolated by the

What is the rate of conduction in nerves? What resemblance is there between nerve conduction and electric conduction? What are the functions of nerve-cells? What conclusion is to be drawn from the anatomical construction of nerve vesicles?

white substance of Schwann. But it is very plain, as many phenomena of the nervous system prove, that there are places of escape for this influence, although it may be confined in the nerve fibre, and these places can be no other than the vesicles. Their caudate aspect, or multipolar form, as it is often termed, will bear no other interpretation. The disturbing influence, coming along the axis cylinder of a nerve fibre, finds itself delivered into the granular material in the interior of a vesicle, a material physically continuous, in the opinion of many physiologists, with the structure of the axis cylinder. Through this granular material the influence is transmitted, and if the vesicle should have on its distant contour two or more nerve fibres connected with it, it would seem to be the necessary result of such a state of things that the influence will pass down all those channels. For these reasons I regard the nerve vesicles as being constructions for the purpose of opening out the closed nerve fibres, and permitting them to deliver their energy into new tracks.

But more than this. Whatever may be the principle by which the nervous influence is propagated, or conducted from point to point of the granular material within the vesicle, there must be now, since there is no structure to prevent it, a lateral spreading of effect. It is not to be supposed that the passage is made in a direct line, from the terminus of the centripetal to the origin of the centrifugal fibre, across these caudate vesicles, and restricted thereto. There is no isolator to confine it in any such track, and it seems to follow of necessity that the whole contents of the vesicle must be affected, and this irrespective of its magnitude. Such a condition of things introduces the suspicion of a second great duty the vesicles may discharge in retaining within themselves, at all events for a short period, the influences that have thus escaped laterally, and thus they become temporary magazines of power. And perhaps this may be the true interpretation of the action of unipolar and bipolar vesicles; the unipolar being a capsule for the collection and conservation of the entire delivered

How are they related in function to nerve-cells? Why must diffusion in the granular material take place? What is the function of unipolar and bipolar vesicles?

influence, the bipolar to admit of the passage onward of a large portion of the force, but by lateral diffusion to preserve or delay a part, and the multipolar at once permitting of conservation and of a discharge into, perhaps, a multitude of new channels.

Upon the same principle that multicaudate vesicles permit of the escape of nervous influence from the single channel in which it has been coming into many new ways, so likewise they must be the seats of the interference of influences delivered into them from many centripetal fibres at the same time. Thus we may imagine a tricaudate vesicle into the granular material of which an influence is delivered simultaneously by two centripetal fibrils, and these, reacting on one another in the interior of the vesicle, give rise to a resultant differing from them both, and this is passed on through the third, the centrifugal fibril.

Regarded in this way, the function of a nerve vesicle may therefore be stated to be, 1st. To permit the escape of an entering influence out of the solitary channel in which it has been isolated into any number of diverging tracts; 2d. To combine influences entering it from various directions into a common or new result; 3d. By permitting of lateral diffusion to take off and keep in store for a certain duration a part of the passing influence.

Our attention can not fail to be arrested by this last effect; for if there be a property characteristic of the nervous mechanism in its utmost degree of development, it is this of retaining the relics or traces of impressions formerly made upon it. As it goes on increasing in complexity as we rise through the animal series, the provision for the retention of such impressions becomes more and more strikingly marked. Ganglionic masses, which, from their position and structure, are marked out for this duty, appear in that ascending scale in increasing magnitude. To these we may aptly apply the designation of registering ganglia, since they truly store up the traces of ancient impressions and keep them in reserve. These ganglia must, moreover, be the scenes of

How is it that interference of influences may take place? What are the three chief functions of vesicles? What are registering ganglia?

the interaction and interference of the impressions they thus contain.

The registering ganglia thus introduce the element of time into the action of the nervous mechanism. The impression which without them would have forthwith ended in action is delayed for a season, nay, perhaps even as long, though it may be in a declining way, as the structure itself endures; and with the introduction of this condition of duration come all those important effects ensuing from the various action of many received impressions, old and new, upon one another.

The action of every ganglionic mechanism depends upon the existence of certain physical conditions, among which, as being of paramount importance, one may be discerned. It is the due supply of arterialized blood. If this be stopped but for a moment, the nerve mechanism loses its power, or if diminished, the display of its characteristic phenomena correspondingly declines. If, on the contrary, the supply be unduly great, or its oxidizing power artificially increased, there is a more energetic action. This latter condition of things is presented in the earlier stages of the respiration of protoxide of nitrogen, an increased muscular power, and an exaggeration of the processes of intellection. The opposite state is witnessed when carbonic acid, more or less dilute, is breathed, from that blunting of the intellectual faculties and indisposition for muscular exertion felt in ill-ventilated apartments where carbonic acid is permitted to accumulate, to the profound torpor and insensibility experienced when it is in a more concentrated state. These exaltations and depressions of the capabilities of the nervous instrument are, therefore, clearly of a chemical kind, and may be produced artificially and at pleasure by the respiration of appropriate gases or the administration of certain drugs. Nay, even the accumulations of the effete products of the economy are sufficient to give rise to such diminutions of power, as we see when bile or urea is permitted to accumulate in the blood. The therapeutical and toxicological influences of certain medicaments are illustrations of these

How do they introduce the element of time? Under what condition do nerve centres act? What ensues when protoxide of nitrogen is breathed? What when carbonic acid?

principles. Of such substances, some act on the sensorial and some on the motor powers.

The copious distribution of arterial blood to the nervous centres indicates that they undergo a rapid waste. That supply can not be for the mere purposes of growth alone, since, when once maturity is reached, the nervous mechanism presents but little expansion. The provision for nutrition assures us that that action must be rapidly going on; but the equilibrium of the system betrays that such nutrition is not for development, but for the repair of waste; and, indeed, this waste proceeds at such a rate that there arises in some portions of this system a necessity for periodic repose or sleep, a time for the restoration of the parts. If any arguments were required to establish beyond dispute that such a disintegration of the material of the nerve centres does occur, it would be furnished by an examination of the urine; for, in nervous substance, phosphorus occurring as a characteristic ingredient, it must give rise to the production of phosphoric acid, or salts thereof, in the supposed periods of activity. Moreover, in this metamorphosis of the vesicular structure ammonia must eventually arise, from the cell walls if from no other source, and accordingly we find in the urine that characteristic double salt, the phosphate of soda and ammonia. The amount of these alkaline phosphates has long been known to be in proportion to the activity of the nervous system, particularly in the case of individuals, as clergymen, whose mental powers are taxed unduly at stated intervals. The general fact that the degree of energy this system exhibits is dependent on the activity of respiration in different tribes of life might be established from many familiar instances.

Vesicular nervous material contains much less fatty matter than the fibrous, but much more water. From this it would appear that the presence of fat in nervous material is functionally connected with its property of conduction or transmission of nervous influence. Every thing seems to indicate that Schwann's white fatty

How is it that the necessity of rest or sleep arises? How is it known that the destruction of nerve material is proportional to its activity? What difference in composition is there between vesicular and fibrous substances?

substance only discharges the physical duty of an isolator.

Our attention may next be directed to the methods of repair of the vesicular structures. Their waste, as just established, implies their repair. Here, as in the muscular tissues, the blood-vessels conduct both operations, and the mode of distribution of the capillaries is such as to bring the circulating current into the most favorable position for discharging this duty. The vesicles are included in the midst of a network of capillaries, and it is believed that there is a resemblance between their mode of growth and that of the cells of the epidermis—that is to say, they arise from nuclei on the spaces nearest to the supply of blood, and gradually undergo development as they prepare for connection with the tubular tissue, assuming the place of cells that have discharged their function and are undergoing disintegration. This gradual passing onward and wearing away recalls the changes in the structure of the cuticle.

To two of the substances thus met with in these examinations of the nervous system our attention may be directed. These are cholesterine and phosphorus. Of the former we can not have failed to remark that it is a constant ingredient in the product of the action of the liver. It is a lipoid, and is found in biliary calculi; and though it may be regarded in one sense as an excrementitious body, since it occurs in fæcal matter, yet it also appears as a normal constituent of the blood. It may therefore be inferred, if the opinion of its existence in the white substance of Schwann be correct, that it is one among the various functions of the liver to prepare this body. Of phosphorus, it might be said that it, among the chemical elements, is most strikingly characterized in its active state by the intensity of its affinity for oxygen. On this depends its quality of shining in the dark, a quality which has given it a name; but by many agents, such, for example, as exposure to a particular temperature, and especially to the light of the sun, it may be thrown into a condition so completely passive

What is the function of the white substance of Schwann? In what manner are the nerve wastes repaired? What analogy does this bear to changes in the skin? What is cholesterine? In what two states does phosphorus occur?

that its chemical energies almost disappear. The doctrine that was presented in explanation of the destruction of one part of the system by the air introduced by respiration while another is protected therefrom, as dependent on the allotropic condition of those parts, is presented here again in discussing the destruction and repair of the nervous tissue; for it is only when it is ready to be removed that the phosphorized constituent assumes the active state, and in so doing gives rise to the development of force. On this view, it would appear that such phosphorized compounds are obtained from the vegetable kingdom in the food in a passive state, the tissues of plants having deoxidized them under the influence of the sunlight, which simultaneously has thrown them into the condition of inactivity, and perhaps it is the assumption of that very condition that is the fundamental cause of their deoxidation.

By the aid of the conclusions we have come to respecting the function of nerve-tubes and vesicles, as shown by their anatomical structure, we shall not have much difficulty in explaining the offices of nervous arcs. The results at which we thus arrive, from a consideration of those cells, are singularly fortified by the electrical experiments of Galvani, Volta, Nobili, and especially those of Volkmann. Among these, the three following are of primary importance:

1st. When a continuous electrical current is passed along a centrifugal nerve, contraction of the muscles which that nerve supplies takes place, and continues as long as the electric current passes, without relaxation, but ceases the moment the current is stopped.

2d. When a continuous electric current is passed through a ganglion, contraction of the muscles supplied by the centrifugal nerves of that ganglion ensues. These contractions do not alternate with relaxation, and on stopping the current the contraction does not cease, as in the preceding case, but is continued for a period of time.

3d. When a continuous electric current is passed down a centripetal nerve, muscular contraction of the

How is it that phosphorus is deoxidized in plants? What three results may be witnessed on passing an electric current through nerves?

parts supplied by the corresponding centrifugal nerves occurs, and these contractions alternate with relaxations.

In view of these facts, we are brought to two conclusions: First, that there is a property in the ganglion, enabling it to hold in reserve a portion of the influence brought into it, so as to keep up the action for a period of time after the original disturbing causes have ceased. Second, that the structure of the ganglion is such as to permit the escape of the coming influence by lateral ways, either periodically or otherwise, and so to produce from a continuous influence an intermitting effect.

Recalling the fact that a ganglion is made up of nerve-tubes and vesicles conjointly, these electrical results must find their solution in the elementary structure of the ganglion—that is to say, in its vesicular portion; for it is not to be supposed that a current of electricity, such as we are here considering, would ever have an opportunity of escaping from the axis cylinder along which it passes. The isolating quality of the white cylinder of Schwann would prevent any such effect. It is not necessary that we should embarrass ourselves here with the fact that electric currents of sufficient intensity could make their way out from the interior channel in spite of its insulating investiture, since it is only with those of a far less power that we have to deal. Arrived in the vesicle, the current at once diffuses itself throughout the granular material, just in the same manner that it would diffuse throughout a spherical conducting mass if brought to it by a wire, and escape therefrom through any number of similar wires that might chance to be in contact with the conducting mass beyond; and though the main body of the current would, as may be readily proved, under these circumstances move in a direct line from the point of entry to the point of exit, there would be, nevertheless, a diffusion of part of it through the conducting mass, no portion thereof remaining unaffected. In a good conductor, such as a metal, this laterally diverging current would instantly escape, but the case becomes very different in the less perfectly conducting material, the granular substance within the cell. As in the secondary piles of Ritter, which, when brought into

What deductions have been made from such experiments? In what manner does diffusion in the vesicle take place?

contact with an active voltaic circle, participate in all its qualities, physiological and chemical, give shocks, produce decompositions, and continue to do so for a time after the original influence has ceased, so a similar conservation occurs in the interior of the vesicle; and this I consider to be the consequence of the difference of structure of the fibrous axis cylinder and the granular vesicle contents. The continuous lines along which the influence has been coming terminate on reaching the vesicle, and are replaced by a divided and inferior conveying structure, a structure which recalls at once the secondary piles of Ritter just alluded to.

As respects absorbed or registered impressions, a few remarks may be here made. There can not be a doubt that the registry of impressions involves an actual structural change in the ganglion, which is of a permanent character. These changes may be rudely and imperfectly illustrated by experiments, such as I published years ago, of which the following may be taken as examples: If, on a cold, polished piece of metal, any object, as a wafer, is laid, and the metal then be breathed upon, and, when the moisture has had time to disappear, the wafer be thrown off, though now upon the polished surface the most critical inspection can discover no trace of any form, if we breathe upon it a spectral figure of the wafer comes into view, and this may be done again and again. Nay, even more; if the polished metal be carefully put aside where nothing can deteriorate its surface, and be so kept for many months (I have witnessed it even after a year), on breathing again upon it, the shadowy form emerges; or, if a sheet of paper on which a key or other object is laid be carried for a few moments into the sunshine, and then instantaneously viewed in the dark, the key being simultaneously removed, a fading spectre of the key on the paper will be seen; and if the paper be put away where nothing can disturb it, and so kept for many months, at the end thereof, if it be carried into a dark place and laid on a piece of hot metal, the spectre of the key will come forth. In the case of bodies more highly phosphores-

What physical contrivance do vesicles in their action resemble? How may invisible impressions be made visible on metallic surfaces? How long will such impressions continue?

cent than paper, the spectres of many different objects which may have been in succession laid originally thereupon will, on warming, emerge in their proper order.

I introduce these illustrations for the purpose of showing how trivial are the impressions which may be thus registered and preserved. Indeed, I believe that a shadow never falls upon a wall without leaving thereupon its permanent trace—a trace that might be made visible by resorting to proper processes. All kinds of photographic drawing are in their degree examples of the kind. Of the moral consequences of such facts it is not my object here to speak. The world would be none the worse if every secret action might thus be made plain. But if on such inorganic surfaces impressions may in this way be preserved, how much more likely is it that the same thing occurs in the purposely-constituted ganglion! Not that there is any necessary coincidence between an external form and its ganglionic impression any more than there is between the letters of a message delivered in a telegraph office and the signals the telegraph gives to the distant station, yet these signals are easily retranslated into the original words—no more than there is between the letters of a printed page and the acts or scenes they may chance to describe, but those letters call up with clearness in the mind of the reader the events and scenes. Indeed, the quickness with which the mind interprets such traces or impressions in its registering ganglia is illustrated by the rapidity with which we gather the sense of a printed page without individualizing each of the letters it contains, or as a skillful accountant runs his eye over a long column of figures, and seems to come by intuition at once to the correct sum.

From the preceding considerations we may infer that there is a necessary limitation of the amount of impressions capable of being registered in the organism, and therefore, in this regard, all human knowledge is finite. Yet its term is much farther off than might at first sight appear. A library of a given size may only be able to contain a given number of books upon its shelves, but the amount of information it is capable of containing

What may be illustrated by phosphorescent surfaces? Illustrate the manner in which impressions may be interpreted. Why may it be inferred that human knowledge is finite?

may be made to vary with the condensation and perspicuity of the books.

In the hypothetical language of physiology, the nervous centres are spoken of as the origin of the nervous influence or force. A close examination of the phenomena they display leads us, however, to receive such a statement with a certain amount of limitation. Most of the ganglia produce no motor impulses except under the action of external impression. Indeed, the cases in which the nervous centres seem to display the quality of spontaneously originating force are so few, and in their nature so doubtful, that we are almost entitled to disregard them. For example, the ganglia of the heart are by some supposed to cause, by their own inherent power, the contractions of that organ, which in cold-blooded animals, long after it has been excised, will continue its rhythmic motions. But it is far more agreeable to the analogies of the nervous system to regard these cardiac ganglia, not as originators of power, but as merely depositories, reservoirs, or magazines of it. There is nothing more extraordinary in their ability to keep up the motions of the organ they are connected with than there is in the subsidiary spring of a chronometer, maintaining the movement of that instrument for the period during which the action of the mainspring is taken off while it is being wound up. Yet the mainspring, and the subsidiary spring too, derive their mechanical power originally from the force which has wound up the chronometer. In this particular of the storing up of power for its utilization in the time of need, the whole ganglionic or sympathetic system of nerves may be taken as the great example.

What conclusions do we come to respecting the spontaneous functions of ganglia? What may be remarked respecting the ganglia of the heart? What mechanical contrivance do they resemble in their action?

CHAPTER XIV.

THE NERVOUS SYSTEM—*Continued.*

The Spinal Cord: its Structure and Functions.—Bell's Discovery.—Reflex Action.—The Medulla Oblongata.—The Pons Varolii.

The Brain: its Structure.—Sensorium.—The Cerebellum: its Structure and Functions.—Symmetrical Doubleness of the Brain.—Double Thought.—Alternate Thought.—Castle-building.—Sentiment of Pre-existence.

The Cranial Nerves: their Functions.

The Great Sympathetic: its Anatomy.—Relation to the Pneumogastric.—Connection with the Spinal System.—Its Ganglia.—They are Reservoirs of Force.—Summary of Functions of the Sympathetic.

We now commence a more detailed examination of the nervous system. This will therefore lead us to speak in succession of the spinal cord and medulla oblongata, of the sensory ganglia, of the cerebellum and cerebrum, of the nerves generally, and, lastly, of the sympathetic system.

THE SPINAL CORD.

The spinal cord is placed in the midst of the vertebral canal. In form it is cylindroid, its section being elliptical, the lateral diameter being the long one. Longitudinally it has two enlargements, one about its upper third, the other toward its termination. Exteriorly it is white, but its section shows a gray substance, arranged in the form of two crescents connected by an isthmus. Above, it is continuous with the brain, which, indeed, is a development upon it, and below it terminates at the cauda equina. Its relative length is much greater in fœtal life, at the third month of which it extends into the sacrum. In adult life it only occupies about the up-

What are the chief general divisions of the nervous system? Describe the construction and position of the spinal cord.

per two thirds of the vertebral canal; it is generally stated that its termination is about the first or second lumbar vertebra. Moreover, it does not fill the vertebral canal, being, by reason of the transverse dimensions of that cavity, rather suspended in than confined by it. The rest of the space, amounting to about one third, is occupied by the roots of the nerves, ligaments, the investitures of the cord, blood-vessels, and a liquid.

With respect to the interior constitution of the cord, it is composed exteriorly of white, and interiorly of gray material.

The spinal cord is surrounded by three membranes, continuous with those of the cranium: the dura mater, the arachnoid, and the pia mater. The latter embraces the cord so closely as to exert a compression upon it. This is shown on slightly wounding it, when the white substance protrudes through the orifice.

From the cord there arise thirty-one pairs of nerves, each nerve having two roots, an anterior or motor, and a posterior or sensory.

The anterior roots issue from the anterior furrow, the posterior from the posterior furrow, where the gray substance emerges. Of the two the latter are the larger, and have more radicles. They also have, in the intervertebral foramen, a ganglion. Beyond the ganglion the two roots coalesce, and the resulting nerve trunk, passing through the intervertebral foramen, divides into an anterior and posterior branch, for the anterior and posterior portions of the body. To this general description there are, however, some exceptions. Thus the posterior root of the first cervical nerve is smaller than the anterior, and very often it has no ganglion. The spinal nerves are enumerated as eight cervical, twelve dorsal, five lumbar, and six sacral pairs.

The white or fibrous portion of the spinal cord is composed in part of the spinal nerve fibres and in part of commissural ones. At one time it was supposed that every one of the preceding continued uninterruptedly

Does the spinal cord fill the entire cavity of the vertebral canal? How are its gray and white constituents arranged respectively? What membranes surround it? How many pairs of nerves arise from it? How many roots have each? What are their functions? Of what is the fibrous portion of the cord composed?

to the brain. On this point, however, the weight of evidence leads us to infer that the vertical distance through which these fibres pass is not very great, and that they are soon brought in connection with the interior vesicular substance. If all the fibres passed uninterruptedly to the brain, we should expect that the cord would increase in thickness by a regular progression upward; but this is not the case. Its enlargements correspond to the number of nerve roots given off from the localities in which they occur.

The determination of the functions of the roots of the spinal nerves by Bell is one of the great discoveries of physiology, and furnishes a solid foundation for an exact knowledge of the functions of the nervous system. The evidence of the truth of the doctrine that the anterior roots of these nerves are motor and the posterior sensory, is complete. Thus, if the anterior root of one of these nerves be divided, all those parts supplied by that nerve will exhibit loss of motion, though their sensation is unimpaired; if the posterior root be divided, the sensibility of the parts is lost, though the power of motion is unaffected. Similar evidence may also be obtained by irritating the ends of the divided roots, muscular motion or pain, as the case may be, being correspondingly observed.

The spinal cord transmits impressions from the periphery to the brain, and conversely enables the brain to bring into action the motor nerves. Division of it at once causes an interruption of voluntary motion and sensation in those parts supplied by nerves below the place of the operation, the functions of the parts above remaining unimpaired. But, though the influence of the brain in exciting voluntary motion, and its capability of receiving sensations, is thus cut off, the severed portion of the cord still possesses an automatic power.

This transmission of influences upward or downward is doubtless, to a considerable degree, accomplished through the vesicular substance, the quality of which, in this respect, has been explained in the preceding chapter. But, besides this, the exterior fibrous struc-

How have the functions of the spinal nerve roots been determined? How are the cord and the brain respectively related to each other?

tures possess a like function, correspondingly as they are connected with the motor or sensory roots of the nerves, the anterior columns being motor, and the posterior apparently sensory.

The spinal cord not only permits the passage of influences in its longitudinal, but also in its transverse direction. This is what might be anticipated from the structure and functions of the cells of its gray interior. If the cord be cut half through in a given place, and again be cut half through on the opposite side, at a little distance above or below, impressions may be conducted through the intermediate portion, the vesicular material being then their only channel.

In a memoir on the distribution of the fibres of the sensitive roots, and on the transmission of impressions in the spinal cord, Dr. Brown-Sequard, referring to the two theories entertained at present—1st. That sensitive impressions reaching the cord pass in totality to the brain along the posterior columns; 2d. That such impressions so arriving pass directly to the central gray substance, which transmits them upward—offers reasons for supposing that both these theories, and especially the first, are contradicted by facts.

It is his opinion that sensitive impressions reaching the cord pass in different directions, some ascending, others descending, but both going in part by the posterior columns, and in part by the posterior gray horns, and perhaps by the lateral columns, to penetrate, after a short distance, the gray central substance by which, or in which, they are transmitted to the brain.

The translation of impressions brought along the centripetal fibres into motions, the exciting influence of which is conveyed along the centrifugal fibres, includes what is understood as the reflex action of the spinal cord as developed by Dr. Hall. Its essential condition is its independence of the agency of the brain, and therefore unconscious nature. As general examples may be mentioned, the movements that occur in swallowing; for aft-

Which are the motor, and which the sensory columns of the cord? What is meant by transverse transmission in the cord? What are the conclusions of Dr. Brown-Sequard as respects the conduction of the cord? What is meant by reflex action? Give instances of the reflex action of the cord.

er the food has been carried by voluntary action into the fauces, its passage onward to the stomach is perfectly involuntary. In like manner, the introduction of air into the lungs in ordinary respiration is involuntary; for though it may be, to a certain extent, under the control of the will, yet that extent is limited, an uncontrollable necessity for the motion presently arising. The action of the valvular arrangements at the cardiac and pyloric orifices of the stomach, and the constant contraction of the sphincter ani, are farther illustrations. To these may be added those impulsive movements we instinctively make on the approach of danger or in the act of falling, and perhaps, too, automatic walking, as we go from place to place in a state of mental abstraction, paying no attention to the course we take.

As above stated, this reflex function of the cord is independent of the brain, though the brain can control it, and this the more perfectly the higher the organization of the animal. Breathing can go on, whether we pay attention to it or not, but we can arrest it if we choose for a time.

In a general way, there is not much difficulty in distinguishing between simple actions of the cord and those in which the brain is participating. In the former, no weariness or fatigue is ever experienced; in the latter it is; and perhaps, even in these last, involving voluntary muscular action, though the control is to be attributed to the brain, the source of the force is in the cord.

From the facts presented by the lower animals, it may be inferred that the spinal cord does not act as a single organ, but rather should be regarded as a collection of ganglia, special duties being discharged by special parts of it.

If the view that has been presented respecting the continuation of fibres from the cord to the brain be correct, these fibres discharge a commissural duty. This would lead us to suppose that there is a correspondence between the functions of the columns of the cord and those of the roots of the spinal nerves, the anterior columns

What is their essential condition? How may cerebral and spinal action be distinguished? Does the cord act as a single organ or as a collection of ganglia? What correspondence is there between the columns of the cord and the roots of its nerves?

being motiferous, or in unison with the motor root of the nerves, the posterior being sensiferous, or in unison with the sensory root of the nerves.

From the point of view thus presented the action of the spinal cord is therefore simple, or it is disturbed by the agency of the brain; in the first case it offers itself purely as an automatic instrument; in the latter, its commissural connections with the brain make a compound apparatus. The former state is closely represented in the construction of the amphioxus, the nervous system of which has no rudiment of a cerebrum or cerebellum; in this animal, therefore, since also the sensory ganglia are merely in a rudimentary state, the mode of life must be purely mechanical, just as it is with an artificial automaton, of which, when a given spring is touched, a given motion is made. Even among the highest vertebrated animals, man himself at the periodic times of quiescence of the cerebrum, as in sleep, when the cerebral influence over other portions is, to a certain extent, suspended, an approach to a similar condition occurs; but in periods of activity of the cerebrum, it can hold the spinal cord in check, controlling, and in some cases arresting its action, and this is done through influences propagated along the structures of the posterior and anterior columns, which therefore are to be regarded, in this respect, as commissures to the brain.

THE MEDULLA OBLONGATA.

The medulla oblongata is a conical body, between the spinal cord and the brain. It is generally understood to be bounded at its upper portion by the pons varolii, but this is not a true limit, since its structure extends through the pons varolii to the crura of the brain. There is the same indefiniteness of limit as respects its lower boundary, which is generally said to be marked by some decussating fibres appearing on its front. Like the spinal cord, it has an anterior and posterior fissure, dividing it into two symmetrical lateral halves; the former is a continuation of the anterior spinal fissure, the latter of the posterior, and ends in the calamus scriptorius above.

State what are the general functions of the cord. What is the position and structure of the medulla oblongata?

The lateral halves thus produced are marked by three grooves, producing four eminences, passing under the following names: 1st. The anterior pyramids; 2d. The olivary bodies; 3d. The restiform bodies; 4th. The posterior pyramids. The anterior fissure is crossed about an inch below the pons varolii by decussating fibres, and hence injuries on one side of the brain produce nervous effects on the opposite side of the body.

Viewed as a superposed continuation of the spinal cord, the medulla oblongata is the tract of communication between that organ and the brain: the anterior pyramids and olivary tracts convey motor influences, and the restiform tracts and posterior pyramids sensations. By experiments similar to those performed upon the cord, these conclusions have been maintained.

But, besides this function of conduction, the medulla oblongata discharges a most important duty as a nervous centre; on it depend respiration and deglutition. The brain may be wholly removed above, and the spinal cord below, as far as the origin of the phrenic nerve, without death necessarily ensuing, but on wounding the medulla oblongata, the muscular movements necessary for the introduction of air are necessarily stopped.

Moreover, the medulla oblongata exhibits the property of reflex action. So far as the function of respiration is concerned, its chief centripetal nerve is the pneumogastric, but the power it possesses is participated in by many others, perhaps by reason of the venous condition into which the blood is brought from want of proper aeration. The violent respiratory movements by the sudden application of cold to the skin, the shower-bath, or dashing cold water on the face, are converted by it into respiratory muscular motions. From it also arise the movements required in the act of deglutition.

Under this view of the functions of the medulla oblongata, it is to be regarded as an exclusively automatic instrument, which can continue its operation after the excision of the brain. As with the spinal cord, so with it: its simple action may continue though its commis-

What are the functions of the medulla oblongata? What relations does it bear to respiration and deglutition? Give some instances of its reflex action. What relation does its action bear to those of the brain?

sural action has ceased, and this either through conditions of disease or by the administration of drugs. In lesions of the brain respiration may still continue, as it may also when sensation and voluntary motion have been arrested by the breathing of chloroform.

THE PONS VAROLII.

The pons varolii consists of a loop of fibres passing from one crus cerebelli to the other, around the tracts of communication between the cord and the brain. That they constitute mainly a commissure for the cerebellum is apparent from the circumstance that, in those animals which have the median cerebellar lobe only, there is no pons, and in other cases its relative magnitude is in proportion to the size of the cerebellar hemispheres.

The functions of the pons varolii are therefore twofold: it acts as a conductor, and also as a nerve centre. In the first respect, it is the channel from the spinal column to the cerebrum and cerebellum, and also between the cerebellar halves, and experiments upon it, in giving rise to sensations and motions, are in conformity with what we should anticipate from the structure and functions of the spinal cord.

In the second respect, as a nervous centre—when the cerebrum and cerebellum are removed, but the pons left untouched, an animal gives tokens of sensation when pinched or irritated, and likewise executes motions having an object; these, however, are no longer observed after the removal of the pons.

THE BRAIN.

The cerebrum and cerebellum, being organs additional to the spinal cord, and developed upon it, the cord being able to discharge its own functions independently of them, we shall find it at once the most natural and most commodious method to consider their structures as arising out of its structure, and their functions as having relation to its functions.

A general idea of the structure of the brain as an ap-

Describe the position and structure of the pons varolii. What are its functions?

pendage to the spinal cord may be gathered by considering that a bifurcation of the fibres takes place in the medulla oblongata, and upon one of the resulting bundles, the crus cerebri, the cerebrum is formed, on the other the cerebellum. The crus cerebri is thus composed of three strands: an inferior, the fibres of which have come from the anterior pyramids, and in part from the olivary bodies. This strand ends in the corpus striatum, its fibres not, however, blending abruptly with the vesicular matter, but passing into it in bundles. It is essentially motor. A superior, derived from the posterior pyramids, and terminating in the thalamus. It is essentially sensory. Between these, constituting the third portion—strand it can scarcely with propriety be called—is a layer of dark vesicular material, the locus niger. It is to be understood that the motor strands of the opposite sides decussate in the medulla oblongata; the sensory strands decussate in the mesocephalon.

The other bundle, arising in the original bifurcation, assumes the designation of crus cerebelli. On it the cerebellum is developed. It consists essentially of fibres from the restiform bodies, re-enforced by others coming from the anterior pyramids under the name of arciform fibres. These together make their way to the interior ganglion of the cerebellum, the corpus dentatum, and there they end. But the crus cerebelli contains likewise two other great strands: an inferior, constituting the commissures of the two cerebellar hemispheres, and which, running round the entire prolongations of the spinal cord, forms the pons varolii; a superior, the processus cerebelli ad testes, uniting the cerebellum and cerebrum.

Of the portions of the spinal cord on which the cerebrum is to be developed, the sensory end in the optic thalamus, the motor in the corpus striatum. The thalamus and striatum of each side may be regarded as one compound ganglion, since, like the columns of the cord, they are entered by a gray and a white commissure. Of the portions on which the cerebellum is to be developed, the termination is in the central ganglion of the cerebellum, the corpus dentatum.

How may the brain be considered as related to the spinal cord? How does the cerebrum arise? How does the cerebellum arise?

At the place of bifurcation of the constituent strands of the crus cerebri and crus cerebelli from each other in the medulla oblongata, there is intercalated or included a ganglion, which, with its apparatus, constitutes the olivary body: its fibres make their way upward between the two preceding bundles, and, having bifurcated, one branch goes to the quadrigemina and the other to the optic thalamus, the latter constituting, as has been said, a part of the crus cerebri. The seat of power of the medulla oblongata is in this ganglion.

Such being the anatomical construction of the crus cerebri, it may be physiologically regarded as a compound strand, the anterior portion being motor, the posterior sensory; and between these a dark vesicular deposit, the locus niger, continuous between the vesicular matter in the spinal cord and that of the thalamus and corpus striatum. From the lowest extremity of the cord to these great ganglia there is, therefore, an unbroken vesicular channel. In its progress onward to the corpus striatum, the anterior strand yields roots of the spinal accessory, hypoglossal, facial, abducens, the small root of the fifth, the trochlearis, and the oculomotor nerves. If there were no other proof of the motor character of this strand, the motor property of all these nerves would be sufficient to determine it. In like manner, the posterior strand yields the pneumogastric, the glossopharyngeal, and the sensory root of the fifth; from the sensory functions of these its sensory character is established.

The layer of vesicular matter found upon the cerebral convolutions, and which is doubtless the seat of the higher intellectual qualities, has therefore no communication with the vesicular matter of the spinal axis, by contact or continuation, but only through the intervention of fibres radiating upon it in all directions from the thalamus and striatum, or rather through some radiating from the great sensory centre, the thalamus, to the periphery of the cerebrum, and others converging from that periphery to the great motor centre, the striatum.

What is the olivary body? What is its function? What is the constitution of the crus cerebri? What nerves come from its anterior strand? What from the posterior? How is the vesicular matter of the cerebral hemispheres arranged?

If the diameter of these fibres be assumed to be $\frac{1}{10000}$ of an inch, there must be many millions of them in the aggregate. The vesicular matter of the hemisphere is arranged on the superficies instead of centrally, on account of the necessities of their structure and condition of activity, for thereby a great surface is obtained; this is farther increased by the artifice of convolutions, a vesicular surface which, counting in that of the cerebellum, has been estimated at 670 square inches, and blood can be copiously supplied and freely removed.

But the thalamus and striatum are only two of a chain of ganglia beneath the cerebral hemispheres. Anteriorly we find the olfactive ganglia, or bulbs of the olfactory nerves, seated upon peduncles, though their character is manifest from the gray matter they contain. Behind these are the tubercula quadrigemina, to which the optic nerves run, and therefore their ganglionic centres. What answers to the auditory ganglion is lodged at a distance back, at the fourth ventricle, and the gustatory ganglion is in the medulla oblongata. These are the ganglia of special sense, and to be regarded as subordinate to the thalamus, which is their common register.

All these parts are commissured with one another, and with their fellows of the opposite half of the brain. Indeed, so likewise are all its parts, the different cerebral lobes, the opposite hemispheres, adjacent and distant convolutions, the cerebrum with the cerebellum. Hence arises a structure of extreme complexity. Among the commissural apparatus may be more particularly mentioned the corpus callosum, the fornix, the anterior, the posterior, the soft, and the superior longitudinal commissures.

The ganglia at the base of the brain are regarded by Dr. Carpenter as constituting the true sensorium, a doctrine he has established by many weighty arguments, and which is doubtless one of the most important thus far introduced by physiologists.

There can be no doubt that the cerebral hemispheres constitute the instrument through which the mind exerts its influences on the body. Any injury of sufficient se-

What are the ganglia at the base of the brain? What are the chief commissures of the brain? What constitutes the sensorium? What is the general function of the cerebral hemispheres?

verity inflicted upon them is at once attended with a total loss of intellectual power; any malformation or lesion by disease is attended by a deterioration below the customary mental standard; any unusual development with correspondingly increased powers of intellection; and this not only as regards animals of different tribes, or individuals at special periods of their lives, but also of different men compared with one another. The general impression that those who have distinguished themselves for mental attainments or intellectual power have been marked by the unusual development of their cerebral hemispheres is founded in fact.

We may therefore consider the intellectual principle as possessing powers, properties, and faculties of its own; as being acted on by impressions existing in the thalamus, and delivered through the intervening fibrous structures to the vesicular material of the convolutions of the cerebral hemispheres. In this region they act upon the intellectual principle and are acted upon by it, the returning influence, if any, coming down through the converging tubular structures to the corpus striatum, and by its commissural connections sent off to particular ganglia, passing along the inferior strand of the crus through the mesocephalon to the anterior pyramids, and by their decussation to the opposite side of the cord.

Having thus spoken of the sensory ganglia and the cerebral hemispheres, it remains to add some remarks respecting the cerebellum. It arises, as has been stated, from the triple strand of the crus cerebelli, of which one layer of fibres is connected with the corpora quadrigemina, and through them with the optic thalami; a second with the restiform bodies; and the third is commissural, and passes forward as the pons varolii.

Like the cerebrum, this organ is vesicular on its surface, with fissures descending to the interior. Their object is apparently the same as that of the convolutions of the brain, the augmentation of surface. Of these fissures, the deep are termed the primary: they divide the organ into lobes. Those descending to a less depth are termed secondary: the divisions they give

How does the intellectual principle operate through the brain? Describe the position and structure of the cerebellum.

rise to are lobules. The gray vesicular material does not, however, descend to the bottom of the primary fissures, and in this respect they differ from the cerebral convolutions. Moreover, from this circumstance, that material is not continuous all over the cerebellum, but is in divided portions.

That the cerebellum is one of the sensory ganglia may be inferred from the history of its development and its anatomical connections. Its median lobe is the first to appear, as in fishes, and the hemispheres arise subsequently as appendages thereto, as in birds. The size these eventually attain gives them a deceptive prominence, and hides their subordinate character. Regarding the lobe, therefore, as the essential and fundamental portion of the structure, the significance of its cerebral connection with the thalamus through the processus ad testes is too obvious to be overlooked. As by this its sensory character is displayed, so the same holds good for the hemispheres, their relations with the spinal cord through the restiform bodies being also of a sensory nature. It seems probable that the superficial vesicular material is in anatomical connection with the thalamus, and the corpus dentatum or inner ganglia with the posterior or sensory columns of the cord.

The co-ordinating and governing minute muscular motions is supposed to be one of the functions of the cerebellum. To maintain the standing position motionless, there are, in reality, a great many muscular movements required, serving to antagonize all the little incidents producing a tendency to fall; and if this be so in standing, how much more difficult must such antagonizing and compensating actions become in walking, running, and such movements. Theoretically, it might be expected that some special organ is necessary to combine such various actions, and that organ seems to be the cerebellum.

Experimental results appear to strengthen this opinion. The cerebellum, on irritation, gives rise to no convulsive motions, nor to sensations. If removed by degrees in successive slices, the motions of the animal be-

What is its essential part? In what manner is it supposed to be related to muscular motion? What experiments have led to that opinion?

come irregular, and, finally, it loses all power of walking or of maintaining its equilibrium.

Connected with these results of experimental lesions of the cerebellum are the rotations, as they are termed, occurring, for example, when one of the crura cerebelli is cut, the animal rolling upon its longitudinal axis for a long time and with great rapidity. From such facts, it has therefore been concluded that the function of the cerebellum is neither for sensation nor intellection, nor is it the source of voluntary movements, but that it is for the government or control of combined muscular action.

It has also been supposed that the cerebellum is for the perception of the sensations derived from the muscles, and enabling the mind to exert a guiding action. The facts supporting the preceding view support this also, there being, moreover, in this case, an additional argument derived from the connection the cerebellum has been shown to maintain with the sensory columns of the cord, and the pain experienced on irritating the restiform columns. It has likewise been pointed out that this hypothesis illustrates the connection between the cerebellum and the optic ganglia, as if it were for the purpose of bringing the organs of sight to the aid of this co-ordination of muscular motion.

A third hypothesis is, that the cerebellum is the organ of sexual instinct, or of amativeness, as it is termed by phrenologists. The evidence of this, when fairly examined, is, however, far from affording a full proof: indeed, in many instances the facts are in direct opposition to the hypothesis. In castrated animals the cerebellum undergoes no diminution. There is no coincidence between the intensity of that instinct in the different animal tribes and the degree of development of this organ; and where it has been in a diseased condition, there has not been a necessary correspondence between the lesion and the loss of the instinct.

In man, the weight of the brain averages about fifty ounces; in females, about forty-five; the maximum be-

What is meant by cerebellar rotations? Why is it supposed that the cerebellum is connected with muscular sensations? What is meant by its being the seat of amativeness? Can that hypothesis be maintained? What is the weight of the brain?

ing about sixty-four, and the minimum about twenty. The mean specific gravity of the gray matter is stated to be, in both sexes, 1.034, but somewhat less early and late in life. The specific gravity of the white is 1.041, and this varies less with sex and time of life than the former.

The functional activity of the brain depends on the copious supply of arterial blood. It is computed that one fifth of the whole quantity in the circulation is sent to this organ. It is delivered through the two internal carotid and two vertebral arteries. The impetus of the current is checked by the sinuous course these vessels take, or by their breaking promptly into capillary branches. A freedom of anastomosis among them, as is well displayed in the circle of Willis, affords abundant provision for accidental stoppages or restraints.

Although the brain is inclosed in an unyielding cavity, it is subject to the pressure of the air. And since the quantity of blood present at any moment in the organ varies with the contemporaneous functional activity, being greater as that activity is greater, the cerebro-spinal fluid also varies in amount. Through this fluid an equality of pressure is therefore insured, no matter what may be the quantity of blood in the brain.

The cerebro-spinal fluid, the quantity of which has been estimated at two ounces, is readily absorbed and as readily reproduced. The act of adjustment between it and the blood requiring a certain period for its completion, the brain can not instantaneously be brought to its maximum action. Thus, as all persons observe, when we undertake any unusual intellectual duty, there is a certain preparatory period to be passed through, as the common expression is, "for composing the thoughts."

Pressure upon the brain, either applied mechanically or through accidental effusions, produces at once functional inactivity, probably by interference with the due circulation of the blood; and, in like manner, any marked change in the chemical relations of that fluid

What is the specific gravity of the brain? What is the relative quantity of blood sent to it? How is that supply furnished and controlled? Does the pressure of the air act on the brain? What is the action of the cerebro-spinal fluid? What are the effects of mechanical pressure on the brain?

exerts on the brain a corresponding effect. Thus, when oxygen gas is breathed, or, still better, protoxide of nitrogen, the processes of intellection go on in an exaggerated way, and ideas in rapid succession, and in unusual forms of combination, flit through the mind; but, as the consequence of this, since the lungs can not remove with the necessary promptness the carbonic acid arising, the narcotic effects of that body are soon experienced; and this is also the case in alcoholic intoxication, in the advanced stages of which the accumulation of carbonic acid in the blood produces the same result.

That different regions of the brain have independent though mutually commissured faculties, is fully established by the phenomena of the nerves of sense, nor can there be any doubt that these differences of physiological function are directly dependent on differences of anatomical structure. It is, indeed, to structural differences that we should impute the greater or less efficiency of the whole organ, as much as to differences of its weight. Because of a higher elaboration, the brain of one person may be more energetic than that of another, even though its weight may be less. It is not to be denied, however, that there is a connection between mental power and the quantity of cerebral matter, when individuals of the same kind are compared, or that in the animal series the psychical powers decline as the cerebrum diminishes in size.

Few topics are more worthy of the attention of the physiologist than that of the variable psychical powers of man, and yet few have been more overlooked. By variable psychical powers I mean those periodicities of increase and diminution in our intellectual efficiency, noticed not only in diseased, but also in healthy states. On the principles we have presented, these find their explanation in the temporary physical states of the organ, such as its condition of repair, its existing facility for oxidation, and the constitution of the blood as respects a proper arterialization.

The most striking structural characteristic of the nervous system is its symmetrical doubleness, the cranial and spinal nerves coming forth by pairs to their distri-

How may it be proved that different regions of the brain have different functions? What is meant by variable psychical powers?

bution on the right and left sides of the body. The manner of development from the spinal axis laterally implies such a construction, and, indeed, gives origin to two halves so equal and alike, that it has often been said each person consists of two separate individuals. Examining those organs which, by reason of the elaborateness of their mechanism and principles of action, enable us to determine with satisfactory precision the function discharged by each one of the members of the pair, as in the case of the eye or the ear, we may come to the following conclusions: Each is a distinct organ in itself, capable of meeting the requirements of the economy in a sufficiently satisfactory manner, and therefore forming a distinct whole; but the pair can likewise act simultaneously, re-enforcing, to a certain degree, each other's power, though in this double action there by no means arises a double intensity of effect. The closure of one ear to a sound does not diminish the loudness by one half, nor does the shutting of one eye reduce to one half the brightness of a light; but, though there is not such a doubling of effect when both eyes or both ears are employed, there is a degree of precision in the resulting indication not to be gained by the use of one of these organs alone. In such a double organ, then, the result is not so much a heightening of the final impression as the giving to it of a greater degree of precision.

Moreover, each organ seems to exert a compensating influence over its fellow in any deficiencies or imperfections it may possess. Thus it is rare that both eyes are of an equal optical goodness, as most individuals will find on making a personal examination; but in vision with both eyes, the faults of the more imperfect one are merged in the indications of the better, and the same might be remarked of the ear; from which it would appear that this doubleness of organs is rather for the purpose of introducing a principle of compensation than one of conspiring action, the object intended to be gained being a justness of perception rather than an increase of effect.

These observations apply to double organs in their

How do double organs act?

normal states, or, if not their normal, their habitual ones; but if to the eye, for example, a temporary disturbance is given, as by pressure, which renders its optical axis oblique, the fellow organ being permitted to retain its usual position, double sight is the result. It is true that, in the habitual divergence of strabismus, such is not the effect, one of the images disappearing, or perhaps the mind, accommodating itself to the habitual condition, combines the two into one. These circumstances indicate that each member of a double organ can, under conditions of disturbance, exercise an independent and even opposing action to its fellow.

It has by some been supposed that the mind pays attention to the impressions of only one of the pair of organs at a time; thus, that we see the images furnished by only one eye, though we can with very great quickness direct attention to those furnished by the other, and therefore, deceived by the rapidity with which this alteration of attention can be accomplished, our belief in the synchronous use of both organs is an error. A simple experiment illustrates this. If the open hand be placed along the nose, so as to divide the right eye from the left, and we look upon the surface of a uniformly-illuminated sheet of paper covered with writing, it will be found that we can only read with one eye at a time, but that the mind can with great rapidity determine which eye it will use. In this experiment we have, moreover, the means of estimating the relative sensitiveness of the two eyes, and other of their optical peculiarities; thus it will be commonly remarked that, though the paper be, as we have said, uniformly illuminated, the part of it regarded by one eye is brighter than that seen by the other, this being due to a difference in their sensibility. It will also frequently occur that the two portions of the page will present different shades of tint, the one, perhaps, being a faint greenish gray, while the other is of a yellowish white.

In this feature of double construction the brain itself participates, presenting a right and left half approaching one another in form, without being absolutely identical. Much, therefore, of what has been said respecting the

What effect ensues from a temporary disturbance of one of them? How may it be proved that one eye is used at a time?

mutual relations of the right and left eye, and the right and left ear, must apply to the right and left hemispheres of the brain. Nor can there be any doubt that each hemisphere is a distinct organ, having the power of carrying on its functions independently of its fellow; that, though each can thus act separately, both can act simultaneously; and, judging from the cases that have just been presented, it would seem that we are justified in inferring that the common action of the two hemispheres is not for the purpose of a heightening of effect, but only for greater precision, and that in the same manner as it is a rare thing to find two eyes or two ears of equal goodness, so also it is unusual to have two hemispheres precisely alike. The defects of the one may be compensated by the superiorities of the other, and thus a mean result be attained; and as one eye or one ear can, under the proper circumstances, overpower its fellow, so likewise can one hemisphere of the brain, except in certain cases, somewhat imaginatively described as insubordination of one of the hemispheres, when insanity is the result, the healthy half being unable to control the diseased one; and for this reason, we often observe of the insane that they have synchronously, or, at all events, in a very rapid alternation, two distinct trains of thought, and, consequently, two distinct utterances, each of which may, so to speak, be perfectly continuous and even sane by itself, but the incongruities that arise from the mingling of the two betray the condition of such persons. In this case doubleness of action is seen in its most exaggerated aspect, but in a less degree, it may be remarked, in the thinking operations of those whose minds are perfectly sound. Thus every student must have observed, when busily engaged in reading, that his mind will wander off to other things, though he may mechanically cast his eyes over page after page; and the same may occur in listening to a lecture or sermon. But, though the insane man may indulge in two synchronous trains of thought, he never indulges in three, for the simple reason that he has not three hemispheres to do it with, the same remark ap-

Does each hemisphere of the brain act independently? What is meant by insubordination of a hemisphere? How may double trains of thought be explained?

plying to the sane man in the accidental wanderings of his thoughts.

The overcoming of this insubordination of one of the hemispheres may, to a very considerable degree, be accomplished by education, of which one of the chief results is that it exercises us in the habit of thinking of one thing at a time, of thinking therefore without confusion, and of arriving at conclusions with precision and decision.

Of the independent and yet complete action of each of the cerebral hemispheres we have abundant and interesting proof. Mental operations can be carried on in a profoundly diseased state of one of these organs, as multitudes of well-authenticated cases attest—nay, *even* when the lesion has gone so far as to amount to an absolute and entire disorganization of one of the hemispheres. Similar evidence is also furnished by interesting cases in which, by accident, as by gunshot wound, destruction of one side has occurred.

Even in a state of health we have numerous examples of this independent action of each hemisphere. *While* engaged in ordinary pursuits implying a continued mental occupation, we are occasionally troubled with suggestions of a different kind. A strain of music, or even a few notes, may be perpetually obtruding, and such an occurrence we could scarcely explain save upon the principle of the separate action of these organs, the one interfering with the other. That precision we have remarked as arising from the conjoint use of two eyes and two ears is doubtless also attained where the two hemispheres are acting in unison. We can, moreover, voluntarily permit one to rest while the other continues its duty, as we can voluntarily make use of one eye, *dis*regarding the indications of the other; but where it is necessary to execute a critical comparison or arrive at an accurate judgment of things, both hemispheres are brought into action, as are both eyes when we intently consider an object.

Among other phenomena, the operation of castle-building, as it is designated, illustrates the voluntary

What effect has education on the use of the hemispheres? How may it be proved that each hemisphere can act perfectly when used alone? Give illustrations of the mixed action of both.

manner in which we permit one hemisphere to act, presenting fanciful delusions; the other, as it were, watching with satisfaction the operation, and in this respect lending itself to it. Not that for a moment we suppose there is any truth in the ideas suggested, and in this the phenomenon differs essentially from that of dreaming, in which it never occurs to us that the scenes and actions are fictitious.

Still more strikingly do those singular cases, from time to time presenting themselves to the physician, of double or alternate consciousness, illustrate this isolated function of the hemispheres. In some of these, each of these portions of the brain has continued its action for a period of days, or even weeks, and then, relapsing into a quiescent state, has been succeeded by the other, thus presenting in some degree an analogy to the facts observed in ordinary cases of insanity, so far as the reciprocating action of the two organs is concerned, but differing in the period of duration of their function; and thus, if one of them should have undergone deterioration, or have suffered lesion, so that it has been reduced to what might be termed an infantile state, the impressions formerly stored up in it having been for the most part lost, or there being an incapacity in it to make use of them, the patient will alternately exhibit what has been aptly termed child life and mature life. For a few days, or perhaps weeks, he will conduct himself in the ordinary manner of an adult, reading, reasoning, and acting, and then, for a similar period, will pass into a condition in which he does not even know his letters, and reasons and acts like a child.

On the same principles an explanation has been given of the sentiment of pre-existence. By this term is understood that strange impression, which all persons have occasionally observed in the course of their lives, that some incident or scene at the moment occurring to them, it may be of quite a trivial nature, has been witnessed by them once before, and is in an instant recognized. Though this opinion that we have seen a present incident once before sometimes occurs in cases where the circumstances are of profound interest to us, the ex-

Explain castle-building. How does double or alternate consciousness arise? What is meant by the sentiment of pre-existence?

perience of most persons assures us that it is more frequently in trivial events. The explanation is, that it arises from the almost contemporaneous action of the two hemispheres, and that, under the circumstances, we have a confusion of memory, and are led to believe that there has been an interval of indefinite duration, when, in point of fact, it was an impression in each hemisphere closely coincident in point of time. Perhaps here we may appropriately recall the well-known fact offered to us in dreaming, that there are circumstances under which our mental operations are carried forward with the most marvelous speed. Thus a sudden sound, a flash of lightning, may be incorporated or expanded into a long dream, diversified with a various multitude of incidents, all appearing to follow one another in an appropriate order, and occupying, as we judge, quite a long time, yet all necessarily arising in an instantaneous manner, for we awake at the moment of the disturbance. Of the same kind is that remarkable deception, authentically related by those who have recovered from death by drowning, that in the last moments of their agony all the various events of their past life, even those of a trivial kind, have come rushing before them with miraculous clearness. Mental operations, therefore, both as regards old recollections and new suggestions, may take effect with wonderful rapidity, and if the sentiment of pre-existence is to be explained on the principle of the double action of the brain, it must likewise be dependent upon the fact here presented.

THE CRANIAL NERVES.

There are twelve pairs of cranial nerves: 1st. The olfactory; 2d. The optic; 3d. The motor oculi; 4th. The pathetic; 5th. The tri-facial; 6th. The abducent; 7th. The facial; 8th. The auditory; 9th. The glosso-pharyngeal; 10th. The pneumogastric; 11th. The spinal accessory; 12th. The hypoglossal.

Of these, the first, the second, and the eighth, being nerves of special sensation, may be more conveniently

How may the sentiment of pre-existence be explained? How is it known that the mind may lose all perception of time? How many cranial nerves are there? Enumerate them. How many are nerves of special sense?

mentioned in connection with the organs of special sense—the nose, the eye, the ear.

The motor-oculi nerve is wholly motor, as may be shown by experiment. When it is irritated the muscles it supplies are convulsed, and when it is divided they are paralyzed.

The fourth nerve, or pathetic, is distributed to the orbital surface of the superior oblique, or trochlear muscle, for which it is the motor nerve. When it is irritated that muscle is convulsed.

The fifth nerve has a construction so closely analogous to that of the spinal nerves, that it has been designated the spinal nerve of the head. It arises by two roots, the anterior of which is the smaller, the posterior having a large ganglion, the ganglion of Casser. From the ganglion three branches diverge, the ophthalmic, the superior maxillary, and inferior maxillary. The last receives the motor portion of the nerve; the first and second branches are sensory, the third is sensory and motor also.

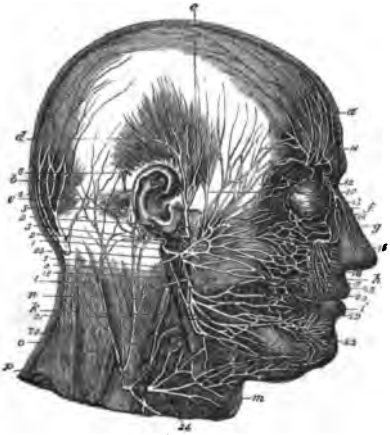
The sixth nerve is known from its origin, distribution, and from experiments made upon it, to be a motor nerve.

The seventh or facial nerve arises from the upper part of the groove between the olivary and restiform bodies, and near the pons varolii. With the auditory nerve, or portio mollis, it constitutes the seventh nerve in the nomenclature of Willis, and derives the name portio dura, under which it sometimes passes, from the density and closeness of its texture. It supplies all the muscles of the face except those of mastication, which are supplied by the fifth nerve, those of the palate, the stapedius, laxator tympani, and tensor tympani; also the muscles of the external ear, and some of those of the tongue. The facial is a centrifugal nerve. If irritated near its origin, there is no sensation of pain; but subsequently it obtains fibres from other sources, as from the fifth and the pneumogastric. After it has been joined by these, irritation is acutely felt. It is therefore to be regarded as the general motor nerve of the

What is the function of the motor-oculi nerve? What is the function of the pathetic? Describe the general construction of the fifth nerve. What are its functions? What is the function of the sixth nerve? Describe the facial nerve.

face, influencing the function of respiration through reflex action, but not being connected with the function of mastication. Injury of it produces paralysis of the parts to which it is distributed, as, for example, the orbicularis palpebrarum, causing inflammation of the eye and opacity of the cornea, through inability of that organ to free itself from dust and spread the lachrymal secretion over its surface. In like manner, the sense of hearing may be injured through loss of control over the muscular structures of the ear, and the acuteness of the sense of smell diminished from inability to introduce the air in a strong current, or the sense of taste, if the point of injury be previous to the giving off of the chorda tympani. In paralysis of the facial nerve the muscles of the face become powerless, and the countenance, therefore, distorted.

Fig. 80.



The facial nerve.

Fig. 80: 1, trunk of the facial at its emergence from the aqueduct of Fallopius; 2, occipito-auricular branch; 3, auricular of the cervical plexus; 4, twig of the occipital muscle; 5, twig of the posterior auricular muscle; 6, twig of the superior auricular; 7, anastomosis of the facial with the auricular of the cervical plexus; 8, branch for the stylo-hyoid and posterior belly of the digastric; 9, temporo-facial anastomosis with the superficial auriculo-temporal of the fifth pair; 10, temporal ramifications of the facial; 11, frontal twigs; 12, superior palpebral twigs; 13, middle palpebral twigs; 14, inferior or motor palpebral twigs; 15, suborbital twigs; 16, suborbital plexus; 17, superior buccal; 18, cervico-facial branch;

What are the functions of the facial nerve? Describe *Fig.* 80.

19, buccal branches, anastomosing with, 20, buccal nerve of fifth pair; 21, mental twigs, forming with, 22, mental nerve of fifth pair, the mental plexus; 23, cervical branches; 24, transverse cervical branch of the cervical plexus; 25, parotid branches of the superficial auriculo-temporal; 26, parotid branches of the facial; *a*, frontal muscle; *b*, occipital muscle; *c*, anterior auricular; *d*, superior auricular; *e*, posterior auricular; *f*, orbicularis palpebrarum; *g*, zygomaticus major; *h*, buccinator; *i*, orbicularis oris; *k*, masseter; *l*, parotid gland; *m*, platysma; *n*, stylo-hyoid and posterior belly of digastric; *o*, sterno-cleido-mastoid; *p*, trapezius.

The ninth or glosso-pharyngeal nerve, examined in the usual way, proves to be a centripetal nerve, having the power of producing reflex motions through the nerves of deglutition, its motor influence being chiefly due to its connections with the pneumogastric and accessory. Though thus a sensory nerve, it is doubtful whether it be the only nerve of taste, or whether that function is not likewise participated in by the lingual branch of the fifth pair. It is certain that section of the lingual does not destroy the sense of taste, and also that those parts of the tongue to which the glosso-pharyngeal is distributed present that sense in the most marked manner. The inference usually drawn is that this nerve and the lingual are both tactile and gustative, and this renders appropriate its description in this place rather than among the nerves of special sense.

The tenth, par vagum, or pneumogastric nerve, arises by six or eight filaments from the groove between the olivary and restiform bodies below the glosso-pharyngeal, and, like it, may be traced to the vesicular material of the floor of the fourth ventricle. It first presents a small ganglion, and soon after a second, nearly an inch in length, called the plexus gangliformis. The nerve then descends the neck in the sheath of the carotid vessels, and in its course differs on the right and left sides respectively. On the right side it passes between the subclavian artery and vein, descending toward the stomach and solar plexus on the posterior portion of the œsophagus; on the left it enters the chest nearly paral-

What are the functions of the ninth nerve? How does the tenth nerve originate? How is it distributed?

lel with the left subclavian, and passes to the stomach and solar plexus along the anterior portion of the œsophagus.

The chief branches of the pneumogastric are the auricular, the pharyngeal, the superior laryngeal, the cardiac, the inferior laryngeal or recurrent, the anterior pulmonary, the posterior pulmonary, the œsophageal, and the gastric.

The pneumogastric presents several plexuses in its course, and, even when distributed on the stomach, exhibits flat, membraniform ganglia. It supplies three great classes of organs: 1st. The digestive, as the pharynx, œsophagus, stomach, liver; 2d. Respiratory, as the larynx, trachea, lungs; 3d. Circulatory, as the heart and great vessels. It associates itself intimately with the sympathetic, and aids it in forming several great plexuses.

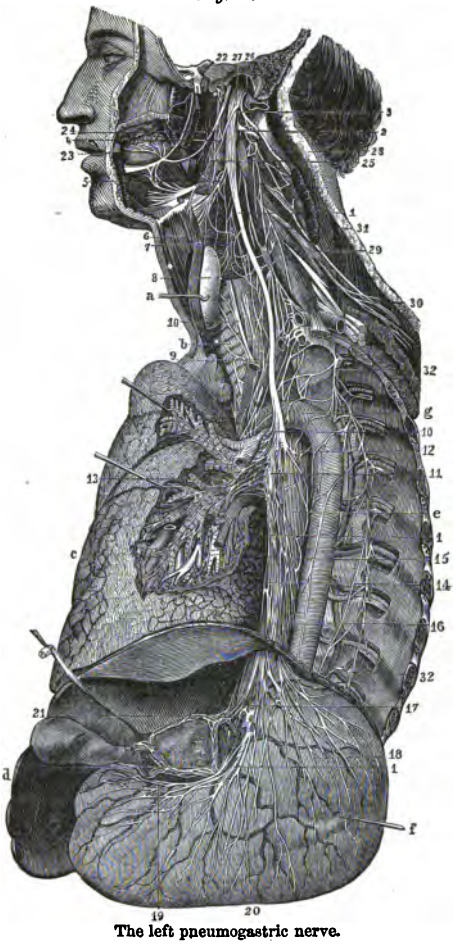
At its root the pneumogastric is sensory, but in its trunk it possesses a double function, arising from its intermingling with other nerves, as the spinal accessory and sympathetic. Though the trunk, if irritated, gives rise to pain, we are not, under ordinary circumstances, conscious of indications, as, for example, in the act of breathing, in which we do not perceive the necessity of respiration, except the access of the air be too long delayed. The pharyngeal branch is the chief motor nerve of the pharynx and palate. The superior laryngeal is the sensory nerve of the larynx, the inferior laryngeal being the motor. Considered along with the spinal accessory, the pneumogastric presents an analogy to a spinal nerve; the accessory constituting the anterior or motor root, and the pneumogastric, with its ganglion, the sensory root.

The pneumogastric nerve was formerly regarded as taking an influential part in the action of the stomach during digestion. The precise nature of its agency in this respect has been already alluded to. In addition, it may be remarked that probably through this nerve is the sensation of hunger conveyed to the mind.

Fig. 81: 1, 1, 1, the left pneumogastric nerve; 2, anastomosis of it with the hypoglossal; 3, anastomosis of

What are the functions of the tenth nerve? Describe *Fig* 81.

Fig. 81.



The left pneumogastric nerve.

plexiform ganglion with internal branch of the spinal; 4, pharyngeal, passing in front of the internal carotid artery; 5, superior laryngeal, behind the internal carotid artery; 6, external laryngeal; 7, laryngeal plexus, formed by external laryngeal and great sympathetic; 8,

superior cardiac; 9, middle cardiac; 10, 10, inferior laryngeal, or recurrent, forming a curve round the arch of the aorta; 11, pulmonary ganglion; 12, its anastomosis with the great sympathetic; 13, posterior pulmonary plexus; 14, œsophageal plexus; 15, curves formed around the œsophagus by the right and left pneumogastrics; 16, œsophageal strand traversing the diaphragm; 17, plexus formed by the strand upon the anterior face of the cardiac end; 18, branches for the great end of the stomach; 19, branches for the small curvature; 20, branches for the anterior face of the stomach; 21, hepatic branches commingling with the hepatic plexus of the great sympathetic, and ramifying in the substance of the liver; 22, glosso-pharyngeal; 23, its lingual branch; 24, pharyngeal branch; 25, branch for the stylo-pharyngeal muscle; 26, spinal; 27, internal branch, aiding to form the pharyngeal nerve; 28, external branch; 29, twig of external branch anastomosing with the third cervical; 30, anastomosis with trapezian branch of the fourth cervical; 31, cervical portion of the great sympathetic; 32, 32, thoracic portion; *a*, thyroid body; *b*, trachea; *c*, left lung, drawn to the right; *d*, liver, raised; *e*, œsophagus; *f*, great end of the stomach, drawn to the left; *g*, arch of the aorta; the carotid, and subclavian arteries, cut.

The eleventh, or spinal accessory, is a motor nerve, as appears from the usual evidence of irritation, and also from its origin and distribution. Its action is not essential in ordinary or involuntary respiration. In voluntary respiration it is brought into play.

The twelfth, or hypoglossal, is the motor nerve of the tongue, irritation of it giving rise to movements throughout that organ, the lingual branch of the fifth being the sensory. The hypoglossal causes the muscles of the neck to aid in the movements necessary for articulate speech.

OF THE GREAT SYMPATHETIC NERVE.

Under the designations of sympathetic, visceral, trisplanchnic, ganglionic, intercostal, or nerve of organic life, passes a series of reddish or gray ganglia, intercon-

What are the functions of the eleventh nerve? What are the functions of the twelfth nerve? Under what names does the sympathetic pass?

nected by nervous strands, extending along each side of the vertebral column, from the head to the coccyx, communicating with all other nerves of the body, and distributing branches to the internal viscera, or organs of involuntary function. These ganglia are less numerous than the vertebræ; the chain on each side communicates with its colleague through plexuses, and the ganglion impar is the common uniting point on the coccyx below. By some it is supposed that the ganglion of Ribes, and by others that the pituitary body has the same function in the cranium above. What are here spoken of as nervous strands are perhaps more correctly prolongations of the ganglia themselves.

The origin of the sympathetic has been long a subject of dispute, some supposing that it is a special system, of which the ganglia are so many independent centres, establishing incidental communications with the cerebro-spinal; others, that its origin is in the internal viscera, and its termination in the cerebro-spinal system, this opinion being supported by the alleged facts that the sympathetic, in its development, appears before the other parts of the nervous system, and simultaneously with the splanchnic organs, and that it has been found in monsters without a brain or spinal cord; others, again, suppose that it originates from the roots of the cerebro-spinal system, and terminates in the interior organs. Regarding it in this light, some have imputed its origin to all the spinal, and fifth and sixth cranial conjointly; others have limited it to the two latter.

The pneumogastric nerve aids it in forming three of its plexuses, the pharyngeal, cardiac, and solar. In certain respects the pneumogastric and sympathetic seem to exhibit a reciprocal development, in some of the lower animals the former predominating over, and supplying the place of the latter; and this replacement, it is said, goes on in the descending series until, in the cephalopodous mollusks, the sympathetic has disappeared, and the pneumogastric takes its place.

Fig. 82 (page 256) illustrates the relation of the sympathetic and spinal nerves: *c c*, anterior fissure of the spinal cord; *a*, anterior root of a dorsal spinal nerve; *p*,

What is its position? How does it originate? What are its relations to the pneumogastric? Describe *Fig.* 82.

Fig. 82.



Relation of the sympathetic and spinal.

posterior root, with its ganglion; a', anterior branch; p', posterior branch; s, sympathetic; e, its double junction with the anterior branch of the spinal nerve by a white and a gray filament.

The sympathetic chain therefore establishes connections with the cerebro-spinal system. Each spinal nerve is brought into relation with it through two strands, a tubular or white, and a gelatinous or gray. The tubular or white strand may be regarded as actually arising from the spinal cord, and consisting of motor and sensory filaments. It makes its way to the ganglion of the sympathetic, passes over and through it, its fibres conjoining themselves with gray ones, which they have gathered in the ganglion. The gray or gelatinous root is to be viewed as having its origin in the ganglion of the sympathetic, and sending its fibres chiefly to the ganglion on the posterior root of the spinal nerve, but few of them doubtfully communicating with the anterior root. The fibres which seem to enter the cord are probably for the supply of blood-vessels. Each of these sympathetic ganglia is therefore a nervous centre, sending forth strands in three directions: 1st. To join the spinal fibres in their distribution; 2d. To the spinal cord itself, or chiefly to the ganglia on the posterior roots of its nerves; 3d. To the next sympa-

How is the sympathetic connected with the spinal system? What nerve supplies originate from the sympathetic ganglia?

thetic ganglion above. In the various plexuses of the sympathetic, vesicles are found, from which gray fibres seem to originate. The branches supplying the viscera constantly form plexuses; the arteries are surrounded with such a net-work. The splanchnic ganglia, with their interconnecting strands, and supplies from the cerebro-spinal, give rise to four great plexuses: the pharyngeal, the cardiac, the solar, and the hypogastric. The first and last of these are in symmetrical pairs; the other two are single, and placed on the median line.

From its construction the sympathetic can not be regarded as an isolated or self-acting system, since all its branches contain fibres derived from the cerebro-spinal. In function it must therefore be adjuvant to that system, and it must be admitted that the motor and sensory qualities of the included spinal fibres, according as they have been derived from the anterior or posterior columns of the cord, are continued in their association with the sympathetic. Hence, in so far as being a compound nerve, it possesses both those functions, and this conclusion is corroborated by such facts as those of the distribution of the sympathetic both to muscular portions, as to the heart, and also to sensitive ones; by the circumstance that the intestinal canal from the stomach to the end of the colon receives its nervous supply from this source alone. Experiments on the sympathetic ganglia establish a similar conclusion, irritation of the cœliac ganglion, for instance, giving rise to increased peristaltic motions, and pathological observations furnishing like evidence as regards the sensory function. Compared with other nerve trunks, the sympathetic is much less active in these respects, a high irritation of the parts supplied by it often being required to cause pain, and, in like manner, its motor fibres are little under the influence of the will.

The sympathetic transmits sensations so tardily that it has been supposed that one office of its ganglia is for the purpose of cutting off such impressions; and, in like manner, when motor fibres of the cerebro-spinal system pass through its ganglia, their conducting power appears to be impaired. There does not seem to be any decisive

What are the four chief sympathetic plexuses? What are some of the chief functions of the sympathetic?

proof that any of the fibres of the sympathetic, properly speaking, are motor or sensory, or that its ganglia produce reflex action, the agency it exerts in these respects on the muscular structure of the heart, blood-vessels, digestive or urinary organs, being due to the associated cerebro-spinal fibres.

In this manner, by its distribution to the arteries, the sympathetic, as a compound nerve, exerts a power over the passage of the blood through them by influencing their contractility, and thereby their diameter. In virtue of this, it therefore affects the rapidity of secretion, and also regulates the rate of nutrition. The entire digestive tract, with its dependencies, is thus brought under its influence, the salivary glands, pharynx, œsophagus, stomach, intestine, nasal, bronchial, and pulmonary surfaces, etc.

The view of the function of ganglia presented on preceding pages is strongly supported by the mechanism and phenomena of the sympathetic nerve. Its ganglia permit the influence passing along the nervous cords to escape therefrom into new channels, and also retain and store up nervous power. They become, therefore, magazines of force, and are hence capable of sustaining rhythmic movements. Even after organs have been exsected, they will still exhibit, under the influence of these ganglia, their accustomed motion, as is the case with the heart, which, in some of the cold-blooded animals, will continue its contractions for many hours after it has been cut out of the body.

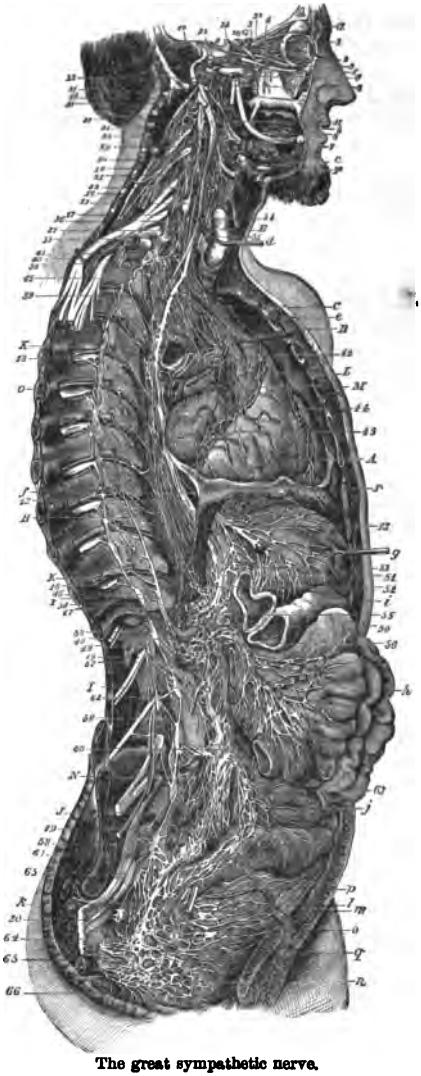
I therefore regard the sympathetic system as having for one of its main functions the equalization or balancing of the nervous force, storing up all transient excesses of it, and furnishing all transient deficiencies. As in a mechanical contrivance, in which the prime mover works in an irregular way, the fly-wheel harmonizes all such variations, storing up or supplying power as the circumstances may require, so does this complicated apparatus act in the mechanism of innervation. And it is worthy of remark, that some such arrangement would seem to be necessary, since the organs of digestion, to

How does it act on the arteries? What are its relations to the digestive tract? What is the physical function of its ganglia? Give a summary of the functions of the sympathetic.

which the sympathetic is so largely directed, are periodically in activity and periodically quiescent.

Fig. 83 (page 260): 1, globe of the eye, dissected so as to show the ciliary nerves; 2, branch of the inferior oblique and the motor root of the ophthalmic ganglion; 3, 3, 3, the three branches of the trifacial, in connection with most of the cranial ganglia, that is, with, 4, ophthalmic ganglion, 5, spheno-palatine, 6, otic, 7, submaxillary, and, 8, sublingual; 9, external motor oculi; 10, facial and its anastomoses with the spheno-palatine and otic ganglia; 11, glosso-pharyngeal; 12, 12, right pneumogastric; 13, left pneumogastric; 14, spinal; 15, hypoglossal; 16, 16, cervical plexus; 17, brachial plexus; 18, 18, intercostal nerves; 19, 19, lumbar plexus; 20, sacral plexus; 21, superior cervical ganglion, furnishing two carotid branches, forming the carotid plexus around the artery of that name, and from which arise the anastomoses with, 22, nerve of Jacobson, 23, carotid branch of vidian nerve, 24, external motor oculi, 25, ophthalmic ganglion; 26, twig for the pituitary gland; 27, anastomosis of superior cervical ganglion with the first cervical pairs; 28, carotid and pharyngeal branches; 29, pharyngeal and intercarotid plexus; 30, laryngeal branch, anastomosed with the external laryngeal of the pneumogastric; 31, superior cardiac nerve; 32, strands of junction of the superior cervical ganglion with, 33, middle cervical ganglion: among the internal branches of the latter are, 34, the anastomotic with, 35, the recurrent nerve, 36, middle cardiac nerve; 37, strand of junction of middle cervical ganglion with, 38, inferior cervical ganglion; 40, twigs furnished by inferior cervical ganglion around the subclavian and vertebral arteries; 41, anastomotic branch with the first intercostal nerve; 42, cardiac plexus and ganglion; 43, 44, secondary plexuses of right and left coronary arteries; from 45 to 46, thoracic ganglionary chain; 47, the great splanchnic traversing the diaphragm, and going to, 48, semilunar ganglion; 49, little splanchnic; 50, solar plexus, receiving, 51, anastomosis of pneumogastric, 52, phrenic nerve; 53, gastric coronary; 54, hepatic; 55, splenic; 56, superior mesenteric, enveloping the arteries of those names; 57, renal plexus; from 58 to 58, lumbar ganglionic chain; 59, lumbo-aor-

Fig. 83.



The great sympathetic nerve.

tic plexus, presenting two enlargements, one, 60, above, the other, 61, below the bifurcation of the aorta; 62, spermatic plexus; 63, inferior mesenteric; 64, hypogastric plexus; 65 to 65, sacral ganglionic chain; 66, terminal coccygeal ganglion; A, heart, slightly turned aside to show the cardiac plexus; B, arch of the aorta, also drawn aside by hook; C, innominata; D, subclavian, cut, to show inferior cervical ganglion; E, inferior thyroid; F, portion of external carotid; G, internal carotid; H, thoracic aorta; I, abdominal aorta; J, primitive iliac; K, intercostals; L, pulmonary artery, of which the right branch is cut; M, superior vena cava, cut at its origin; M, vena cava inferior; O, pulmonary veins; *a*, lachrymal gland; *b*, sublingual gland; *c*, submaxillary gland; *d*, thyroid body; *e*, trachea; *f*, œsophagus, going to, *g*, the stomach; *h*, several intestinal loops with superior mesenteric plexus; *i*, transverse colon; *j*, sigmoid flexure; *k*, rectum; *l*, bladder; *m*, ureter; *n*, prostate; *o*, vesicula seminalis; *p*, vas deferens; *q*, spermatic cord; *r*, *r*, diaphragm.

CHAPTER XV.

OF HEARING.

The Senses: Five Organs of Sense.
Of Hearing.—General Structure of the Organ of Hearing.—Physical Peculiarities of Sounds, Intensity, Time of Vibration, and Quality.—The Tympanum, Cochlea, and Semicircular Canals are for the Appreciation of these peculiarities.

OF THE SENSES.

THE animal being in its highest development, requires means for the perception of time, space, force, and quality. This is accomplished by what are termed the organs of sense. They are five in number: 1st. The organ of hearing; 2d. That of seeing; 3d. That of touching; 4th. That of smelling; 5th. That of tasting. The ear is the organ of time; the eye that of space; the tactile apparatus is for the perception of force; and the

To what functions are the organs of sense respectively devoted?

mechanisms for smelling and tasting conjointly determine the chemical qualities of bodies; that of smelling addressing itself to substances in the vaporous and gaseous state, and that of tasting to such as are liquid or dissolved in water.

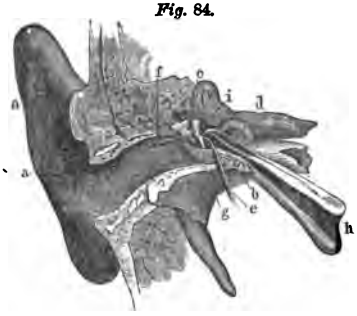
OF HEARING.

The organ of hearing is composed of three parts, the external ear, the tympanic cavity or tympanum, and the labyrinth.

Of these three portions of the ear, the external canal is, of course, full of air, as is also the tympanic cavity or drum; but the labyrinth is filled with a liquid, and in this the terminal filaments of the auditory nerve are placed.

The essential part of the mechanism of hearing is the auditory nerve, which arises from the anterior wall of the fourth ventricle, and then, joining the facial, passes forward upon the crus cerebelli; reaching the meatus, it divides into two portions, the cochlear and vestibular nerves: these subdivide again, and are distributed to the vestibule and cochlea respectively.

Fig. 84.



External, middle, and internal ear.

Fig. 84: *a a*, pavilion and external auditory canal, or external ear; *b*, tympanic cavity, containing the bones; *c*, hammer and its three muscles, viz., *d*, internal muscle, lodged in the thickness of the superior wall of Eustachian tube, and bending at a right angle to be inserted in superior part of handle of hammer; *e*, anterior muscle of hammer; *f*, external muscle of hammer; *g*, interior half of membrana tympani, holding the handle of the hammer; *h*, tube of Eustachius; *i*, internal ear or labyrinth.

Of how many parts is the organ of hearing composed? What media are in the three portions of the ear? What is the origin and distribution of the auditory nerve? Describe *Fig.* 84.

The explanation usually given of the functions of these various parts is as follows: The waves of sound, moving through the atmosphere, pass down the exterior canal and strike upon the membrane of the drum, which is thrown into vibration thereby. The little bones forming a chain from this membrane to the oval one at the back of the drum participate in this movement, and, indeed, serve to convey it, without much loss, across the cavity. Under the impulses thus communicated to it the oval membrane commences to vibrate, and in those movements the water in the labyrinth joins; and so the filaments of the auditory nerve become affected, and the sensation of sound is transmitted to the brain. It is supposed that the three semicircular canals, which are set at right angles to one another, as it were, occupying the three adjoining faces of a cube, are for the purpose of determining in what direction the sound is coming—whether upward, downward, or laterally. Moreover, it is believed that the little muscles which operate on the membrane of the drum have the duty of tightening or slackening it so as to receive the sounding waves in the most available way.

It is not necessary to enter on a lengthy criticism of this explanation. Physiologists have long regretted that it assigns no use for many of the most complicated and delicate arrangements connected with the ear, offers no explanation of the manner in which that intricate organ is enabled to present to the mind the various relations of sound, and is inconsistent with many of the facts of comparative anatomy.

What are the physical peculiarities existing in the waves of sound? They are these three, 1st. The intensity, that is, loudness or feebleness of the sound; 2d. Its note or pitch; 3d. Its quality; for two sounds of the same intensity and note may differ characteristically. The sound of the violin differs from that of the flute, and this, again, from that of the human voice. Our organ of audition is so constructed that it is affected by each of these peculiarities, and transmits them to the mind. All mathematicians who have written on the sub-

What is the common hypothesis of audition? What are some of the defects of this hypothesis? What are the three physical peculiarities of sound?

ject of sound agree in setting forth the three peculiarities that have been mentioned, intensity, note, quality, as the grand features of waves of sound, and this upon a mere abstract discussion of acoustics. Now these three essential, abstract, or theoretical peculiarities of sound-waves are the very three which the organ of hearing seizes upon. Premising the remark that mathematicians have abundantly proved that the intensity of sounds depends upon the amplitude of excursion of the vibrating particles, and the pitch or note upon wave length, I shall now proceed to offer some arguments in proof of the proposition that the triple function of the ear is discharged in the following way: 1st. That the drum is for the measurement of the intensity; 2d. The cochlea for the recognition of wave length; 3d. The semicircular canals for the appreciation of quality.

1st. On the measurement of the intensity of sound, structure of the tympanic cavity or drum, and its functions.

The tympanic cavity, or drum of the ear, is an air cavity of a cylindroid and flattened shape, in the petrous portion of the temporal bone. Outwardly it is bounded by the membrana tympani, and on other sides by the petrous bone: it is crossed by a chain of bones, three in number, and named the malleus or hammer-bone, the incus or anvil, and the stapes or stirrup. The Eustachian tube affords a channel of communication from the interior of the drum to the pharynx. Moreover, there is a communication with the mastoid cells, but the Eustachian tube is the only outlet to the atmosphere. The whole cavity of the tympanum is lined with mucous membrane and ciliated epithelium, which is also reflected over the bony chain. Upon the inner wall of the tympanum are two chief apertures, the fenestra ovalis and the fenestra rotunda, each closed by membrane. The chain of bones is attached at one end by the handle of the malleus to the membrana tympani, at the other by the foot of the stirrup to the membrane of the fenestra ovalis.

It is to be remarked that the membrana tympani is placed obliquely at the bottom of the external canal.

What is the function of the drum of the ear? What is that of the cochlea? What is that of the semicircular canals? Describe the structure of the drum?

In a hollow bone, rising upon the interior wall of the tympanum, and called the pyramid, the stapedius muscle is placed. Through a little aperture at the apex of the pyramid its tendon goes out, and is inserted in the neck of the stapes. Its action seems to be to make pressure on the membrane of the fenestra ovalis, but as it does this, it tilts the stapes into an oblique position. A second muscle, the tensor tympani, is attached in front to the under surface of the petrous bone, and is inserted in the short process of the malleus; when it contracts it makes tension upon the membrana tympani, drawing it more tightly inward. It is to be especially remarked of both these muscles that they are voluntary; that is, of the striated variety.

The tympanum is for determining the first property of sounding waves, that is, their intensity.

It has been proved that when the tension of the membrana tympani is increased, sonorous undulations pass with less readiness through it. Indeed, this may be verified by personal experiment, as when, by a strong effort of expiration or inspiration, the mouth and nostrils being closed, we compress air into the tympanic cavity or withdraw it therefrom through the Eustachian tube, and thereby stretch the membrana tympani outwardly or inwardly, the hearing at once becomes indistinct, and sounds are enfeebled.

Under natural circumstances, a stretching of the membrane inwardly is accomplished by the contraction of the tensor tympani muscle, the stapedius holding tight contemporaneously on the loop of the stirrup, and preventing disturbance of position of the bony chain at that end, and hindering any outward bulging of the membrane of the fenestra ovalis. When, therefore, the soniferous waves impinge upon the membrana tympani, they tend to throw it into vibration; the tensor tympani contracts to such an extent as to bring the membrane to a standard of tension, and, since this muscle is of the voluntary kind, the mind judges of the degree of force required to produce that result just as, when we lift from the ground bodies of different weights, we judge with a certain

What is the action of the stapedius and tensor tympani muscles? What is the effect of changing the tension of the membrane of the drum? Describe the action of its muscles.

precision of the degree of force necessary to be put forth. The condition of contraction of the tensor tympani therefore enables the mind to measure the intensity of the sounding waves.

But this muscular contraction is strictly a reflex act, and is therefore preceded, as all such acts are, by an impression. That impression is made, as we shall presently find, primarily on the auditory nerve. But, since these reflected acts are not sensory, the mind has no knowledge of the effect impressed in this respect upon the auditory nerve, and only becomes sensible of it in an indirect way, through the contractions ensuing in the tensor tympani muscle.

In this view of the case, the use of the Eustachian tube becomes obvious; it is to form a ready passage for the air inwardly or outwardly, so that no condensation or rarefaction shall occur within the tympanic cavity; for such rarefactions and condensations would disturb the action of the contracting muscle, and make it yield a false estimate. Besides this, the Eustachian tube, as has long been known, affords an outlet for mucus.

The function of the ossicles is therefore rather for the purpose of tension than of conduction, though it is not denied that sounds may pass readily along them. They are to be regarded as aiding in the perfection of auditory perceptions, but yet not as being absolutely essential to the appreciation of sounds, or even of their finer modifications. Whatever affects the facility of vibration of the membrana tympani, such as its thickening, or stiffening, or unusual dryness, will render the hearing dull, but the membrane itself may be perforated, or even undergo extensive lesions, without any apparently corresponding effect. But if the stapes be injured or be removed, deafness is at once the result.

There is nothing remarkable in the precision with which the contractions of the two muscles acting on the membrane of the drum are made. The same precision is illustrated in the case of the muscles of the vocal cords. The state of these may be determined to the $\frac{1}{17000}$ part of an inch.

How is it that the mind perceives their state? What is the use of the Eustachian tube? What is the function of the ossicles? With what precision may the contractions of the muscles of the vocal cords be estimated?

It might perhaps be inquired, Why should not the function of determining the intensity of sounds, as well as their wave length, be imputed directly to the auditory nerve? It is with the ear as with the eye, the mechanism for determining wave length can only act with uniformity when the agent to be measured is reduced to a standard intensity. A bright light falling upon the eye brings on a contraction of the pupil. And so with the ear. A partial deafening must be established to adjust the intensity of sound, that the auditory nerve may act under standard circumstances. The primary impression therefore made upon that nerve by the loudness of sounds is, so to speak, consumed by being converted as a reflex act into motion, because there is a necessity that the tensor and stapedius should move, and reflex acts do not affect the mind, but it instantly perceives the condition of contraction of those muscles, and so estimates the intensity of the sound.

2d. On the measurement of wave length, or time of vibration of sounds. Structure of the cochlea and its functions.

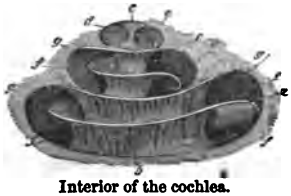
The cochlea has been described as resembling a snail's shell in appearance. It is a conical tube, wound spirally, and making two and a half turns. The interior of this conical and spirally-winding tube is divided throughout its length into two portions by means of a transverse partition, which, following the spiral winding of the tube, has had the name of lamina spiralis bestowed on it. The two partitions produced by the intervention of this lamina are called scala vestibuli and scala tympani. At the top or point of the helix the two scalæ communicate through a little hole, from the cessation of the lamina spiralis. To this opening or deficiency the name of helicotrema is given. Considering the two scalæ as separate tubes, their mouths open differently; the scala vestibuli opens into the vestibule of the labyrinth, and we may therefore regard the membrane of the fenestra ovalis as being virtually its boundary or closure, but the mouth of the scala tympani is against the fenestra rotunda, and is closed by the membrane of that aperture. As their names therefore indicate, the scala vestibuli opens

What analogy is there between the pupil of the eye and the drum of the ear? Describe the construction of the cochlea.

into the vestibule, and the scala tympani into the tympanum.

Passing directly through the body of the cochlea, and being, as it were, the core upon which that structure is built, is a bony cone, called the modiolus. Indeed, the bony part of the transverse plate separating the tube of the cochlea into its two scalæ might be regarded as a spiral process of the modiolus. Through the modiolus and its spiral process, or lamina spiralis, the auditory nerve gains access, through suitable channels, to the interior of the scalæ.

Fig. 85.



Interior of the cochlea.

Fig. 85, interior of the cochlea, rendered visible by the removal of half of the outer wall: *a a*, lamina spiralis, turning by its inner edge, *b*, around the axis of the cochlea; *c*, infundibulum; *d*, aperture of communication between two scalæ; *e e*, section of the outer wall; *f f f*, inferior or tympanic scala; *g g g*, superior or vestibular scala.

It is necessary to understand the structure of the lamina spiralis more particularly. As we have said, it divides the helical tube into the two scalæ by extending transversely across it. Its bony portion does not, however, extend more than about one third of the distance, the rest of it being made up in part of a delicate membranous portion, and completed by a muscular structure; so that, if we consider the lamina spiralis at any point, the region of it near the modiolus is bone, the intermediate portion membranous, and the residual muscular. Or, considering the lamina spiralis in the aggregate, we might say that it consists of a helix of bone, membrane, and muscle. To the muscle the name of the cochlearis is given. Its obvious function is to tighten the membranous region. Moreover, considered thus in the aggregate, the lamina spiralis is a triangular plate wound round upon a central conical core, and, therefore, broadest at the base of the cochlea, and gradually tapering off toward the apex. It is to be understood that the

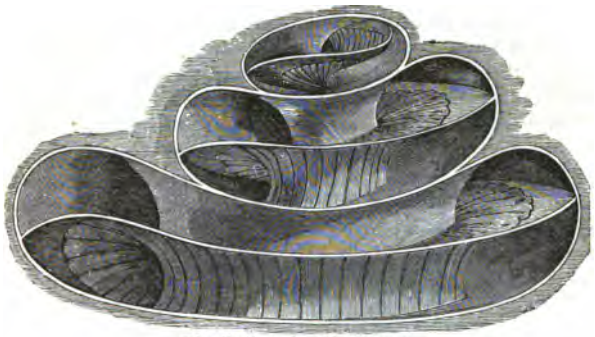
How is the auditory nerve introduced? Describe *Fig.* 85. What is the construction of the spiral lamina?

cochlea, like all other portions of the labyrinth, is filled with water.

Upon the spiral lamina, issuing forth through its bony portion, are placed the ultimate filaments of the auditory nerve. These, having cast off their white substance, come into relation with elongated vesicles, and are thus distributed upon the membranous portion, the membrane being kept uniformly tense by the action of the cochlearis muscle.

Fig. 86, section of the cochlea, magnified six diameters, to show the distribution of the cochlear branch of the auditory nerve.

Fig. 86.



Distribution of cochlear nerve.

The principles of acoustics would lead us to infer that sounds entering the cochlea throw into vibration its spiral lamina, an inference supported by anatomical considerations in regard to the position and function of the cochlearis muscle in keeping the membranous portion of the lamina at a due degree of tension. We should also infer that each external sound does not throw the lamina into vibration throughout its whole length, but only on a special and corresponding point, and thereby affects solely the filament of the auditory nerve in connection with that point; that sounds which are low will act upon the broader portions of the membrane, near the mouth of the cochlea, and those which are high, the narrower portions near the apex. In this respect, there-

How is it kept tense? Describe *Fig.* 86. How is it that the auditory nerve is affected?

fore, the function of hearing should have two limits, one for low and the other for high notes, as experience proves to us is actually the case; but possibly the scale is, so to speak, enlarged through the various degrees of tenseness which may be given by the contractions of the cochlearis muscle. A general idea of the nature of this limited vibration may be obtained by recalling the effect produced when one musical instrument is played in the vicinity of another, as when, for example, a flute is played near to a piano-forte, the strings of the latter are thrown into sympathetic vibration, and the piano emits a note answering to each note of the flute. All the strings are not thrown into vibration at once, but for each note of the flute that string of the piano in unison vibrates.

In the view here presented, I consider that each external musical note causes a special portion of the spiral lamina to vibrate, and that the particular nerve fibril supplying that portion is affected thereby, and thus a distinct sensation is communicated to the brain, the nerve fibrils to the right and left of the one affected lying at rest. It may probably be that the denticulate structure has for its duty the more perfect production of this isolated effect, or that the teeth thereof act like the dampers of a musical instrument, and restrain the vibration. Notes the wave length of which is great, or, what is the same thing, the times of the vibrations of which are long, affect those portions of the spiral lamina which are broad and near to the base of the cochlea, but notes whose wave lengths are short, and times of vibration correspondingly brief, affect those portions near to the apex. But probably the scale is changed, as before said, by the tension of the cochlearis muscle, and thus the same part of the lamina can take charge of a range of many octaves.

It may be inquired how it is that a sound passing through the auditory canal, the bones of the tympanum, the membrane of the fenestra ovalis, and thus affecting its destined portion of the lamina, does not give rise to an idea in the mind of repetition or reverberation by

Why are there two limits in hearing? What physical illustration of the action of the spiral lamina may be given? What is probably the use of the denticulate structure? How may several octaves be perceived?

moving back and forth through the two scalæ, and affecting its proper nerve fibril at each passage. Is there not a necessity for the existence of some mechanism of interference to destroy the wave after it has once done its work? Admitting the force of such inquiries, we can not avoid being impressed with the fact that the two scalæ of the cochlear tube present all the aspects of a mechanism constructed for the discharge of such a duty. For interference to take place among undulations of any kind, waves upon water, sounds in the air, or the ethereal undulations constituting light, the essential condition is that they shall run through paths of a certain unequal length. They must also be brought, for a full practical effect, to their common point of encounter under a very acute angle, and these conditions are represented in the scala vestibuli and the scala tympani, which are of unequal length, placed at such an acute angle to one another that they might almost be said to be parallel, occupied by a fluid of the same density, and through both at the same moment are passing the undulations constituting the same sound, one having been communicated by the fenestra ovalis, the other through the fenestra rotunda, their common point of convergence, and perhaps of mutual destruction, being at the helicotrema, the aperture at the apex through which they intercommunicate. Nor can we fail to be struck by the circumstance, if this explanation of the function of the scalæ be correct, in what an admirable manner the whole instrument is provided with self-adjusting power, since, when the stirrup forces in the membrane of the fenestra ovalis, the pressure communicated through the water pushes out the membrane of the fenestra rotunda, and thereby the relative length of the two scalæ has changed, the one having become longer by as much as the other has become shorter, an adjustment necessary to bring about total interference at the helicotrema. And we might add that such a construction is all the more interesting, for, since it is the intensity of the waves that is to be destroyed, reliance is had upon the intensity instrument, the drum, to pro-

What is the function of the scalæ? How is the relative length of the two scalæ made to change? Why is interference of the received sound necessary?

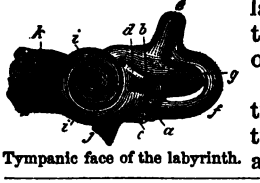
duce that effect, and it is done by the contractions of the tensor tympani and stapedius muscles. Perhaps the perfect accomplishment of this interference is the standard, to which allusion has been made before, by which the mind judges of the power put forth by those muscles, and thereby of the intensity of the sound.

3d. On the determination of the quality of sounds, the structure of the semicircular canals, and their function.

The semicircular canals are cylindroid tubes, developed, as it were, from the vestibule, and of a figure which has suggested their name. They are three in number, and placed at right angles to one another; two of them are vertical, the third horizontal; they all open into the vestibule, the adjacent branches of two of the coalescing first. On one of the branches of each of them there is a dilatation just before it joins the vestibule; to this dilatation the designation of ampulla is given. The vestibule of the labyrinth may therefore be regarded as the common mouth of the semicircular canals, and of the scala vestibuli of the cochlea; or, considering its order of development, the vestibule may be regarded as the essential portion of the labyrinth, and the semicircular canals and cochlea appendices that have branched forth from it.

The vestibule and semicircular canals are lined with a membrane which, of course, copies their shape, yet it is not in contact with their bony walls, but is parted therefrom by a stratum of water; to this the name of perilymph is given; their interior is also filled with a liquid—the endolymph it is called. The bony structure is called the bony labyrinth; this structure is the membranous labyrinth. A portion of the auditory nerve divides into three main branches, which present themselves for the supply of the ampullæ: the brush-like terminations of these are accommodated with an otolith, or ear-stone.

Fig. 87.



Tympanic face of the labyrinth.

Fig. 87: *a*, external wall of vestibule, on which is seen, *b*, fenestra ovalis; *c*, fenestra rotunda, and, *d*, tract of the facial nerve;

What are the semicircular canals? What are the perilymph and endolymph? Describe *Fig.* 87.

e, superior semicircular canal; *f*, posterior semicircular canal; *g*, horizontal semicircular canal; *i i*, wall of the cochlea; *j*, aqueduct of cochlea; *k*, portion of petrous bone.

The explanation usually given of the function of the semicircular canals is, that they serve to determine the direction of sounds, an idea originating from their remarkable rectangular position. However, this is accomplished in almost all cases by directing the external canal toward the point from which the sound is coming, and judging of its place by the variations of its intensity. Animals commonly direct the external ear toward the sounding point, guided doubtless in the same way. Some physiologists have restricted the use of the semicircular canals to the collection of those sounds which strike upon the skull, but, besides the preceding considerations, there are others derived from comparative anatomy indicating that this can scarcely be their duty.

The intensity of sounds is judged of by the tympanum; their pitch or wave length is determined by the cochlea, and therefore there arises a strong presumption that the semicircular canals must have the function of distinguishing the third characteristic of sounds, that is, their quality; since, if this be not the case, there seems to be no other portion of the auditory mechanism to which that office could be assigned.

The suspicion we are thus led to entertain, that the semicircular canals are for appreciating the quality of sounds, is strengthened in no common degree by facts of comparative physiology. Unfortunately, we know so little of the mechanical peculiarity on which distinctions of quality depend, that we are wholly unable to trace out the structural conditions of an organ calculated for seizing on them. We know that the quality of a note emitted by a violin is different from that emitted by a flute, though the intensity and pitch may be the same, but we can not tell why. In the case before us, we therefore can expect no assistance in the way of arguments from mechanical philosophy, and are limited to

What is the common opinion of the use of the semicircular canals? Give reasons for supposing that they are really for estimating the quality of sounds. What is meant by the term quality of sounds?

the use of those which may be drawn from comparative anatomy and physiology.

Examining, therefore, what appears to be the primitive plan of the construction of this mechanism, we find it to consist of a nerve fibril in connection with an otolith, or little stony body. Such a construction, included in a bag of water, constitutes, in point of fact, the organ of hearing of some of the lower tribes, as the gasteropodous molluscs. These animals can have no perception of the pitch of sounds or musical notes, and only an imperfect one of intensities. But what they do distinguish is one noise from another. Now the idea conveyed to the mind by difference of noises is precisely the distinction that we are dwelling on, that of quality.

If, instead of restricting our examination to the semicircular canals, we extend it to the whole organ of hearing, and consider together, in the case of each animal tribe, its requirements, and the manner in which those requirements are satisfied, we shall meet with a surprising confirmation of the preceding views. The lowest requirement we can conceive of is the appreciating of noises; an advance upon this is the determination of their direction; a higher advance, the determination of their intensity; and a still higher, the recognition of those combinations of impulses constituting a musical sound. For each of these successive requirements the auditory mechanism must necessarily become more complex; and thus it first appears, as we have just stated, as a sac of water, containing a stony grain or otolith imbedded in the œsophageal collar. A noise agitates the otolith, and by its movement the perception of a sound ensues. In cephalopodous mulluscs the auditory sac is detached, and the intercommunicating thread represents the rudiment of what, in the higher grade of development, will be the auditory nerve. With another advance the sac is lodged in a cartilaginous cavity. Thus, in the cuttle-fish, a simple cartilaginous vestibule exists, having within it a membranous bag or auditory capsule, filled with fluid, and upon the capsule the filaments of the auditory nerve are spread. An otolith or

How may that conclusion be illustrated from comparative anatomy? Give a general view of the auditory mechanism. Describe the comparative anatomy of the ear.

ear-stone is placed within, and this constitutes the entire apparatus, while yet there is no vibrating membrane and no fenestral aperture.

Even in still higher conditions the purely mechanical character of the structure is manifest, and so, in some of those in which the sac opens exteriorly, grains of sand, that have been introduced by chance from without, rest on the hair-like filaments which the auditory sac contains, each filament apparently including a nerve fibril. In a still higher condition of advance, as, for example, in the lobster, a portion of the shelly wall forming the boundary of the auditory cavity is unconsolidated, and a membrane stretching over the otherwise vacant space presents the first rudiment of the fenestra ovalis. With the exception of the amphioxus, all vertebrated animals have a special organ of hearing, which, in successive tribes, presents an interesting increase of complexity, beginning in the cyclostomes with a sac in the cranial cartilages filled with water, nerve fibrils distributed on its walls, and an otolith included, but no external communicating aperture. From this, in succession, the various portions to be developed in perfection in the higher races gradually appear: the myxine has one semicircular canal arising from the vestibule, the lamprey has two, the higher forms have three. As the case may be, a portion of the cartilage or bony parietes is deficient, and, again, the fenestra ovalis is the result. Though in the osseous fishes there is neither tympanum nor cochlea, in some few the rudiments of the former begin to exist. The naked amphibia have no cochlea, and only one fenestra, answering to the ovalis: to this is fitted a stapes; but in lizards and scaly serpents there is a general advance, these having a conical cochlea. As we pass through them the plan is carried out; the tympanic cavity and its chain of bones, the Eustachian tube, and cochlea appear; and with the rudiment of the cochlea there is presented in the tympanic cavity a second aperture, answering to the fenestra rotunda. In birds the structure offers a continued improvement, commencing on a plan analogous to that of the scaly amphibia, but exhibiting a speedy development. The mem-

In what order are the parts of the ear developed in the animal series?

brana tympani is composed of several layers; the cavity of the drum communicates with cells in the cranial bones, the analogues of the mastoid cells; a bony Eustachian tube crosses to meet its fellow of the opposite side, and open in a common aperture. The ossicles consist of a malleus, a staff-shaped intermediate bone, and a flat stapes, resting on the fenestra ovalis. As if to show a tendency to the form it is eventually to assume, this bone sometimes presents a forked appearance, the preparation for a stirrup shape. As regards this bone, birds and mammals may be said to overlap, for in its more developed condition in birds it bifurcates, but in the lower mammals, as the kangaroo, it is still cylindric. In birds of prey the semicircular canals are large, the cochlea fairly developed, though as a straight or slightly-curved tube, containing its scalæ and vibrating lamina: the vestibule has ear-stones. Through the monotremata this condition of construction is continued into the perfect mammals: all the aerial tribes have external ears, and full development is reached in the auditory mechanism of man.

Now if we collate the facts here presented with the requirements of the condition of life demanded by each of these successive races, we shall find that the remark heretofore made, that the semicircular canals are for the recognition of the qualities of sound, is strikingly borne out, though, from our ignorance of what it is in which quality consists, we are wholly unable to offer an explanation of the precise mode of action of that part of the auditory mechanism.

We are so prone to extend our ideas of our own perceptions to the case of other animals that it may not here be unprofitable to offer a remark serving to correct such views. To many of the sounds we are familiar with, birds and other lower tribes are totally deaf; they can not appreciate, except within a narrow range, the notes of music, and, indeed, to all those in which there is no cochlea such notes are inaudible. In the lower grades nothing more than a noise can be detected, and that doubtless in a very indefinite way. We can there-

How do these facts bear on the interpretation of the use of the semicircular canals? Why is it that all inferior animals are partially deaf?

fore understand how, through imperfection of construction, they are cut off from the perception of an infinite number of occurrences obvious enough to us. Even among our domestic animals, to which we so often speak or sing in the way we do to one another, the intellectual obtuseness we think we recognize doubtless originates in an incapacity to receive those expressions, because of faulty structural condition.

CHAPTER XVI.

OF VISION.

Perception of Warmth.—Structure of Ocelli.—Use of Lenses.—Physical Principle of the Organ of Vision.
Description of the Human Eye.—Optical Action of its Parts.—Spherical and Chromatic Aberration.—Receiving Screen of the Eye is the black Pigment.—Long and short Sight, and their Correction.
Nervous Mechanism of the Eye: its Structure and Functions.—Manner of Perception by the Retina.—Ocular Spectra.—Erect Vision.—Idea of the Solidity of Bodies.
Accessory Apparatus of the Eye.—The Eyebrows.—Eyelids.—Lachrymal Apparatus.

In the animal series, long before any thing like a distinct organ of vision can be detected, there is a perception of light and darkness. The hydra, a fresh-water polype, offers an example, for this animal seeks the sunny side of the vessel in which it is placed, preferring it to the shade. In the absence of a visual organ, there can not be a doubt that its movements depend on the perception of warmth, just as when a man who is totally blind passes from the sun into the shade, his feelings at once notify him of the change.

Dr. Franklin made an experiment to the following effect. He placed on the snow, on a sunshiny winter day, pieces of cloth of different colors—black, yellow, white, etc., etc.—in such a position that the sun's rays fell

What is the first indication of the perception of light? Describe Dr. Franklin's experiment.

equally on them. After a certain length of time, on examining them, he found that the black cloth had melted its way deeply into the snow, the yellow to a less depth, and the white scarcely at all. He therefore drew the conclusion that, when they are receiving light, surfaces become warm in proportion to the depth of their tint, and that, of all surfaces, one having a velvety blackness is most sensitive, because it can exert the most powerful absorbent agency.

On this principle the ocelli of the lower tribes are constructed. They consist of a collection of pigment granules, usually of a red, black, or dark color, seated on the expansion of a nervous thread. The principle contained in this mechanism is that of relieving the general surface from the impression of light, or rather of rendering it more intense by centralizing it upon a special locality. Such a construction involves at once a change in the nervous mechanism, by devoting a particular system of nerve tubules to the new duty. But, notwithstanding this increasing complexity of structure, the physical principle is still as simple as before. It is indeed almost as though a blind man should paint upon his skin a black space, so that, as in Franklin's experiment, it might be more sensitive to the sun. With this devotion to a new duty the nervous tubules doubtless assume an isolated function, and thus there arises a nerve of special sense. The ocelli of the lower animals are sometimes quite numerous. From this a new power is at once derived, the power of determining the position of the source of light, a property doubtless becoming more perfectly marked in proportion to the number and symmetry of arrangement of the ocelli. As we ascend the animal series in our examination, we soon find that complexity is being introduced. A membranous hood, arising from a little fold of the external tegument, shadows forth the rudiment of an eyelid, and seems to indicate to us that, even in these low grades, the condition we shall eventually find so strikingly marked in the high ones already exists, that functional activity involves destruction, and that the sensory mechanism must have its period of repose.

How are ocelli constructed? What advantage is gained from having them symmetrically arranged?

Approaching the more highly-developed conditions of the organ of vision, we may next consider the cases presented by the eyes of insects and the eyes of higher mammalia. In these a new physical principle has been introduced, the optical property of the convex lens, a transparent solid, having one or both of its surfaces curved, and obtaining therefrom the power of forming representations, or images of objects in front of it, at a certain focal distance behind.

The instrument known as the camera obscura represents the optical construction of the eye. Upon a receiving surface or screen, placed at the focal distance behind its lens, images are depicted of whatever objects may chance to be in front; but—and this is a remark of interest to us now—the visual range, or field of view, is quite limited. In animals, the perfection of whose vision requires that, instead of being restricted in their view to a narrow space, they should be able, as it were, to take in almost a hemisphere at a glance, this extension of the visual function can only be accomplished in one of two different ways. To use the illustration we have been employing, it may be attained by having innumerable cameræ pointing in innumerable directions, and conveying the resulting images to one common surface; or by having one, or at most two, cameræ set upon a movable stand, which can quickly point them in any direction, and so enable them to inspect successive fields of view with almost instantaneous rapidity. The former plan is resorted to in most insects, the latter in man. In insects, the immobility of the head upon the trunk would interfere with any rapid rotation of the visual organ; in man, the facility with which rotation can take place upon the neck as on an axis, and the movement of the eye in its orbit, accomplishes the object without any kind of difficulty.

In continuing an investigation of the structure of the eye, it is convenient to consider it under three heads: 1st. Its optical mechanism; 2d. Its nervous mechanism; 3d. Its accessory apparatus.

What is a convex lens? What is meant by its focal distance? Describe the use of the camera obscura. By what methods may an increased field of view be obtained?

1*st. Of the Optical Mechanism of the Eye.*

The human eye is of a globular form, and about one inch in diameter. It is not perfectly spherical, its lateral diameter being shorter than its antero-posterior by about one twentieth part. It may be described as consisting of three coats, which, forming a shell, contain transparent media and the optical apparatus. It might also be considered as arising from an expansion of the optic nerve into an almost spherical cavity, and which, being fortified by certain tissues behind, has a dioptric mechanism in front.

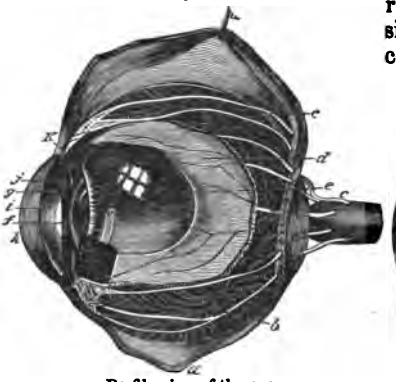
The coats of the eye are three in number: the sclerotic, the choroid, and the retina. The sclerotic is the exterior. It is a white fibrous membrane, very tough, and possessing the necessary resistance to give mechanical protection to the parts within. Within this is the choroid, a vascular layer or tunic, presenting on its interior the black pigment which darkens the interior of the eye. The innermost coat is the retina, an expansion of the optic nerve. The sclerotic coat is perforated in front, and into the circular aperture so arising the transparent cornea is let, like a watch-glass. Many anatomists, however, consider that the cornea is absolutely continuous with the sclerotic, and a part of it; the sclerotic and the choroid are united round the edge of the cornea by the ciliary ligament. The iris is perforated in its centre, the aperture being designated as its pupil. Posterior to the iris is the crystalline lens, the space between the lens and the cornea being filled with the aqueous humor, in which the iris floats, dividing it into two regions, called, from their position, the anterior and posterior chambers. All the rest of the globe between the back of the lens and the retina is filled with a substance extremely transparent, and known as the vitreous humor. The aqueous humor, the crystalline lens, and the vitreous humor, by reason of their transparency, offer, therefore, no obstacle to the passage of light.

Fig. 88: *a a*, sclerotic, turned over; *b*, choroid; *c c*, ciliary nerves traversing sclerotic, and going between it and choroid; *d*, retina; *e*, vitreous body; *f*, crystalline;

What is the form and size of the human eye? How many coats has it? How are they arranged?

g, middle section of iris; *h*, middle section of cornea; *i*, anterior chamber; *j*, posterior chamber; *k*, canal of Fontana, between the ciliary circle and iris on one side, and sclerotic and cornea on the other.

Fig. 88.



Profile view of the eye.

Fig. 89.

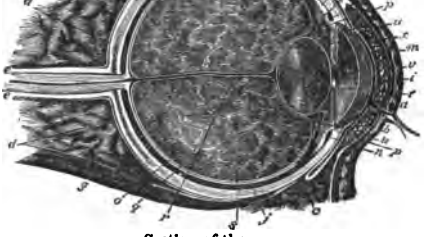


Front view of the eye.

Fig. 89; *a*, transparent cornea; *b b*, sclerotic; *c*, iris; *d*, pupil; *e*, ciliary circle; *f*, choroid, on which is seen the dichotomous termination of the ciliary nerves; *g*, ciliary processes; *h*, crystalline.

Fig. 90: *a*, upper eyelid; *b*, lower eyelid, showing the different layers composing them; *c c*, conjunctiva,

Fig. 90.



Section of the eye.

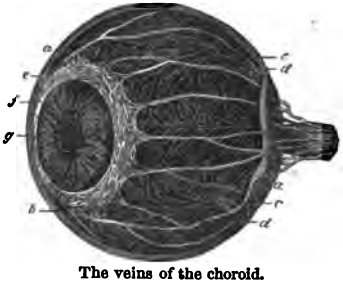
reflected from posterior face of eyelid upon the anterior face of the globe of the eye; *d d*, orbito-ocular aponeu-

Describe *Figs.* 88, 89, 90.

rosis, prolonged upon *e*, the sheath of the optic nerve, and sending sheaths to the muscles; *f*, the superior rectus; *g*, the inferior rectus; *h h*, sclerotic, re-enforced behind by sheath of optic nerve, and in front by aponeurotic expansion of recti muscles; *i*, transparent cornea, cut to show its lamellar texture; *j j*, choroid; *k*, ciliary circle; *l*, ciliary body and processes; *m*, iris and pupil; *n n*, canal of Fontana; *o o*, retina, continuous with substance of optic nerve; *p*, ciliary circle of Zinn; *q q*, hyaloid membrane; *r*, capsular artery, lodged in hyaloid canal; *s s*, vitreous humor and its cells; *t*, crystalline and its capsule; *u u*, canal of Petit; *v*, anterior chamber; *x*, posterior chamber.

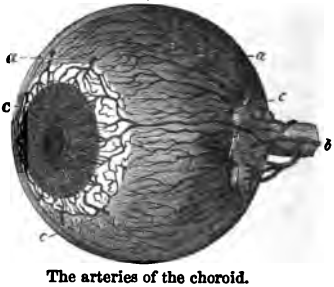
Fig. 91: *a a*, section of sclerotic; *b*, exterior surface of the choroid, on which are seen, *c c*, the vasa vorticosa; *d d*, ciliary nerves; *e*, ciliary ligaments; *f*, anterior face of iris; *g*, pupil.

Fig. 91.



The veins of the choroid.

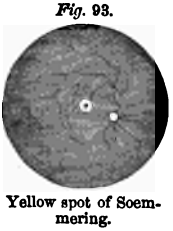
Fig. 92.



The arteries of the choroid.

Fig. 92: *a a*, exterior surface of the choroid and the iris, showing the arterial network of these two membranes, supplied by the ciliary arteries, which, after having traversed the sclerotic, divide into *b b*, posterior ciliaries for the choroid, and *c c*, anterior ciliaries for the iris.

Fig. 93.



Yellow spot of Soemmering.

In the optical axis of the eye there is upon the retina a spot of about the twentieth of an inch in diameter, called the yellow spot of Soemmering. Its position is shown in *Fig.* 93. The en-

Describe *Figs.* 91, 92, 93.

trance of the optic nerve is at the spot marked at some distance on one side.

Of the Optical Action of the Eye.

It is the province of the works on natural philosophy to explain how, when rays of light fall upon a convex lens, or upon combinations of such lenses, an inverted image of the object will form at the proper focal distance. For the purposes of physiology, it is sufficient to receive this as a fact, easily illustrated by observing the inverted images of external objects depicted upon a sheet of white paper when a convex lens or magnifying-glass is held at a particular distance between the object and the paper.

In making such an experiment, some other facts interesting to the physiologist may be readily demonstrated: 1st. That the focal distance, that is, the distance between the lens and the paper, is variable: it is greater for objects that are near, less for those that are remote; 2d. That lenses of different curvatures being compared together, the flatter ones have the longest focus for objects at the same distance; 3d. That lenses of the same focus, but of different diameters, give images unequally sharp, an indefiniteness being perceived in the image given by the lens of large diameter. This indistinctness is due to the spherical figure of the lens, and would not have occurred had the surface been ground to another conic section. It is called spherical aberration; 4th. Unless the lens be of very long focus, or its aperture or diameter be very small, the edges of the images it yields will be fringed with rainbow colors, and thereby a second cause of indistinctness arises. It is called chromatic aberration. This aberration may be destroyed by properly combining together lenses made of different refracting media, and with surfaces of suitable curvatures; a combination in which this has been effected is termed an achromatic lens; and if, at the same time, by proper arrangements, the spherical aberration has been destroyed, the lens is termed aplanatic.

Now the aqueous humor, bounded by the cornea in

What is the optical action of a convex lens? What is meant by spherical aberration? What is meant by chromatic aberration? What is an aplanatic lens?

front and the crystalline lens behind, acts as a convex, and therefore converging lens, and to this effect the crystalline itself adds powerfully, the two conjointly causing the images of external objects to form upon the black pigment. These images are, of course, inverted.

The adjustment of the eye for perfect vision of objects at different distances is accomplished by the action of the ciliary muscle, the requisite movement being to draw the lens farther from the black pigment when the object is near. There has been a difference of opinion as respects the actual screen upon which the images form. Some of the early optical writers regarded the black pigment as being that receiving surface, an opinion almost universally abandoned, the function having been of late attributed to the retina, but, as it appears to me, on totally insufficient grounds. The arguments against the retina, both optical and anatomical, are perfectly unanswerable. During life it is a transparent medium, as incapable of receiving an image as a sheet of clear glass, or the atmospheric air itself; and, as will presently be found, when we come to describe its structure, its sensory surface is its exterior one, that is, the one nearest to the choroid coat. But the black pigment, from its perfect opacity, not only completely absorbs the rays of light, turning them, if such a phrase may be used, into heat, no matter how faint they may be; it also discharges the well-known duty of darkening the interior of the eye, and therefore preventing indistinctness through the straying of the rays of light. Perfection of vision requires that the images should form on a mathematical superficies, and not in the midst of a transparent medium. The black pigment satisfies that condition, the retina does not.

Spherical aberration is compensated for partly by the increasing density of the lens toward its centre, and partly by the action of the iris, which stops such rays of light as are at any considerable distance from the axis of the eye, acting in the same manner as a perforated plate or diaphragm in ordinary optical instruments. It does not appear that there is any attempt at cor-

What are the convergent media of the eye? How is adjustment for distance accomplished? What is the receiving screen of the eye? How is spherical aberration corrected?

recting the chromatic aberration of the eye, though it is popularly supposed that the cornea, the aqueous humor, the lens, and the vitreous humor act together in the same manner as the different pieces of glass in an achromatic arrangement. Optical reasons, however, founded upon the constitution and refractive powers of those substances, lead us to abandon that view, and in a theoretical respect to regard the eye as imperfect in this particular.

Adjustment for the variable intensity of light is effected by the dilatations and contractions of the iris, the pupillary opening of which varies from the $\frac{1}{20}$ to the $\frac{1}{3}$ of an inch in diameter. We are thus enabled to bring to the same degree of illuminating effect upon the retina lights differing in brilliancy in the proportion of one to forty-five.

In what has been said, reference is made to a perfect eye; but imperfections are very common. Two may be more particularly pointed out—long-sightedness and short-sightedness. In the former, objects, to be seen distinctly, must be placed farther off than the usual distance; in the latter they must be brought nearer. Long-sightedness arises from the flatness of the lens or cornea, so that the focal images given do not fall truly on the black pigment, but would be, at a certain distance, exterior to it; hence the indistinctness that results. Short-sightedness is due to an excess of curvature in the cornea or lens, the rays forming their focal images before the black pigment is reached. The former defect may be removed by the use of convex lenses as spectacles, the latter by concave. It is often said that short-sightedness is a defect of early life, long-sightedness of old age. However this may be in another respect, it is not so optically. Indeed, cases sometimes occur in which one eye is affected with the former and the other with the latter difficulty. Very frequently the two eyes, compared together, will be found differently advanced in their degree of imperfection, and hence the difficulty of obtaining a pair of spectacles, though the selection is attempted to be made out of a large assortment. In

Is the chromatic aberration corrected? What is the adjustment for variation of brightness? What are long and short sight? How may they be corrected?

such cases, each eye should be accommodated with a lens to suit itself.

Compared with the organ of hearing, the eye is much more limited in its action; for, while the ear can distinguish sounds varying through many octaves, the eye can only perceive vibrations which, to use the language of acoustics, differ by a single octave only. To one octave, therefore, its range is limited.

The eye is limited in another respect; it can not simultaneously compare lights differing from one another in brilliancy if the one should be upward of 64 times as bright as the other. The more luminous overpowers or extinguishes the feebler. We can not see the light of a candle if we hold it up against the sun. I may refer to the experiments I have published, establishing that upon this fact is founded the most exact method of photometry yet known.

2*d*. *Of the Nervous Mechanism of the Eye.*

The retina, commonly described as an expansion of the optic nerve, intervenes between the vitreous humor and the choroid coat.

Regarding it as composed of distinct layers, the innermost of which, in contact with the hyaloid membrane, is called the fibrous gray layer, arises from the tubules of the optic nerve, which have cast off the white substance of Schwann; and in passing, we may dwell emphatically upon the point that at that spot, where it exists alone, that is to say, where the optic nerve is entering the eye, vision can not be performed. Beneath, or outside this fibrous layer, comes the gray vesicular layer: it is analogous to the vesicular matter of the brain. The two layers thus far described are served with capillary blood-vessels of extreme minuteness. Outside of the gray vesicular layer is the granular layer, which, as its name imports, consists of a congeries of granules, probably the origin of the vesicles, new ones arising from this layer continually. Yet again, outside of the granular layer, comes a delicate sheet, known as the membrane of Jacob, but formed, in reality, from the

What is the limit of vision? What is the limit in variations of brightness? Describe the construction of the retina? What is Jacob's membrane?

juxtaposition of a set of rod-shaped and conical bodies, the thicker ends of the rods being outward, the thinner inward.

It is to be particularly remarked that the sentient or receiving part of the retina is the posterior, or that which is in contact with the black pigment.

The second pair of nerves, from which the retina is thus derived, are, from their function, designated the optic nerves. They do not enter the sclerotic in its optical axis, but at a little distance on one side, and obliquely—a provision doubtless intended, in a measure, to avoid the occurrence of the blind spot on the centre of the field of vision, and to place it unsymmetrically in the two eyes, so that each eye shall compensate the defect of the other.

Besides the optic nerve, which is exclusively the nerve of vision, the collateral parts of the eye are supplied from various sources. Of these nerves, the functions are very various; some are for the movement of the ball, or for general sensibility of the surface, or for the movements of the eyelids, or for those of the iris, and some for the lachrymal apparatus.

Of the Function of the Nervous Mechanism of the Eye.

Reasons have already been given for considering that it is the black pigment which acts as the receiving or optical screen, and not the retina. If no other argument was adduced for departing from the opinion usually expressed, attributing this function to the retina, the thickness of that structure would be sufficient; images can only form with precision or sharpness upon an abrupt surface. And since it is now indisputably ascertained that both the chemical effect and the heating effect of the rays of light depend upon their absorption, those effects being in direct proportion to the completeness of the absorption, we are justified in inferring that, since the eye is sensible to rays of a very low intensity, and to each of the colored ones equally, its screen of reception must not only be a superficies, but likewise a black one. Such a surface the black pigment is. In the case of al-

Which layer of the retina is its sensitive one? How are the optic nerves arranged? What other nerve supplies are given to the eye? How is it certain that the black pigment *is* the receiving surface?

binos, and animals having the black pigment imperfectly developed, the receiving surface or screen is still the interior of the choroid. Under such circumstances, vision must be indistinct.

Recalling what has been said respecting the diffuse sensibility of the lower members of the animal series to light, and the structure of ocelli, it accords well therewith to consider that the primary effect of the rays of light upon the black pigment is to raise its temperature, and this to a degree in relation to their intensity and intrinsic color; light of a yellow tint exerting, as has been said, the most energetic action, and rays corresponding to the extreme red and the extreme violet the feeblest. The varied images of external objects thus painted upon the black pigment raise its temperature in becoming extinguished, and that in the order of their brilliancy and color; the pigment thus discharging a double duty, as a surface of extreme sensibility for calorific impressions, and also as darkening the interior of the globe.

In this local disturbance of temperature, in my opinion, the act of vision commences, this doctrine being in perfect harmony with the anatomical structure of the retina, the posterior surface of which is its sensory surface, and not the anterior, as it ought to be if the explanation usually given of the nature of vision be correct; and therefore, as when we pass the tip of the finger over the surfaces of bodies, and recognize warm and cold spaces thereupon, the same occurs with infinitely more delicacy in the eye. The club-shaped particles of Jacob's membrane are truly tactile organs, which communicate to the sensory surface of the retina the condition of temperature of the black pigment.

But this communication of a variation of temperature implies a variation in the waste and repair of the retina itself, for there can be no doubt that all such changes are accelerated by an increase of heat, and diminished by its decrease. And though in this manner the origin of the action which has been set up is calorific, and therefore physical, it immediately becomes converted into a physiological equivalent in the metamorphosis and destruction of a nervous tissue.

What is the effect of heat upon it? Describe the mode of perception by the retina?

The eye can not perceive rays coming from a source the temperature of which is lower than 1000° F., for such rays can not pass through a stratum of water or through the humors of the eye. Natural philosophers, in making a distinction between light and heat, have too often overlooked the fact that, though thermometers are sensitive to rays of every sort, the eye is not. Its indications are complicated by the necessary introduction of absorbent media, which stop all rays of low refrangibility.

The impression arising from the disturbed condition of the retinal vesicles is carried by the optic tubules to the chiasm of the two nerves. Apart from the general facts elsewhere presented by physiology, the existence of a blind spot at the entrance of the optic nerve, where there is a necessary absence of vesicular structure, is a clear proof of the insensibility of the tubular structure to the influence of light. Considering, therefore, the retina as typically composed of three layers, one of tubules, one of vesicles, and one of granules, and these in health being perfectly transparent, the luminous beams pass through them just as they do through the atmosphere, without exerting the slightest effect; and as, when those rays strike the opaque surface of the earth, or are absorbed by the sea, heat is disengaged and effects ensue, so likewise, when they have reached the black pigment, the changes I have been designating arise. The vesicular layer undergoes rapid metamorphosis, the effect of that change is transmitted by the tubular layer, and in the granular the germs are constantly arising from which the waste of the middle layer is repaired. So, therefore, the tubular layer is for conduction, the vesicular layer for waste, the granular layer for repair; and now appears the significance of the construction and proximity of the choroid coat, for the waste of the vesicular layer can not occur save under the oxidizing influence of the arterial blood, nor can the nutrition of the granular layer be accomplished except under the same condition. Moreover, the resulting products of waste require to be quickly removed, and it is not possible to conceive the construction of an arrangement better adapted for this triple object

Why can not the eye perceive rays issuing from a source lower than 1000°? What is the function of the two chief layers of the retina and of the choroid?

than that which the choroid presents. On the old view of the nature of vision, the construction of the choroid seems to be without significance.

The effect thus communicated to the vesicular layer of the retina, through the intervention of Jacob's rods and cones, is now carried along the nervous tubules out of the globe of the eye. The nerves from each eye, converging, encounter one another at the chiasm. Here it is, however, to be understood that, while the proper optic tubules of the right eye go to the left brain, and of the left eye to the right brain, the anterior band of commissural tubules brings the two eyes into a special relation with one another, the right side of one eye corresponding with the right of the other, and the left with the left; or, to put the same statement under a more simple yet more instructive form, the outer side of one eye corresponds with the inner of the other, and in this manner the two retinæ become as if they were virtually incased the one within the shell of the other, an arrangement obviously compensating in a degree for the blind spot of each eye, and, indeed, eliminating the effect of all accidental irregularities, for numberless such irregularities must exist, there being a necessity, for example, that blood-vessels should cross through the sensitive to the conducting structures, and such blood-vessels give rise to lines of inertness.

From this commissural arrangement it comes to pass that each retina possesses regions of symmetry with the other, and on this singleness of vision depends; each point of the outer portion of the retina of the right eye has its point of symmetry in an inner portion of the left, and when from a distant object rays fall on these symmetrical points, that object will be seen single; but if, by the pressure of the finger or otherwise, we compel the image to fall in one of the eyes upon another, and, therefore, non-symmetrical point, the object at once becomes double. It should be remarked that this exchange of symmetry concerns only the lateral divisions, for the upper portion of one eye corresponds with the upper portion of the other, and the lower with the lower.

Impressions made upon the retina do not disappear

Describe the interconnection between the right and left eye. What is its result? Explain the cause of single and double vision.

instantly, but gradually fade away, and in so doing occupy a certain period of time, varying with the brightness of the original light, the existing condition of the eye, and the illumination to which it is exposed. This duration of impressions is commonly estimated at about one third of a second. It is a phenomenon analogous to that of the continuance of sound in the ear, and subserves an important purpose of keeping vision continuous and distinct during the winking of the eyelids. Commonly it is illustrated by referring to the familiar experiment of a stick lighted at one end and twirled rapidly round, which gives rise to the appearance of a continuous fiery circle. Many ingenious and interesting toys, such as the thaumatrope or wonder-turner, act on this principle.

There have been few optical problems more warmly contested than that of erect vision. The image at the bottom of the eye is inverted, but we see the object upright. Some have supposed that we really see things upside down, but have learned to correct the error by the sense of touch. Doubtless the true explanation is to be found in the anatomical construction of the eye. It should be borne in mind that there is a very wide difference between the image formed at the bottom of an eye as we look at it, and, if such an expression may be used, as the eye itself looks at it. We see it from behind, the retina sees it from the front.

The stereoscope shows to what an extent our ideas of the solidity of objects depend on the differences of the images in each eye. By reason of their difference of position, each of the two eyes will have a different picture upon its black pigment of any solid object, and the mind, combining these dissimilar pictures into one, gathers therefrom the idea of solidity. If thus we offer to the eyes two pictures of a given object, presenting the same form as that object would have done when seen from each eye respectively, the mind combines these flat pictures together, and can not divest itself of the idea of a solid body. This is the principle of the stereoscope.

The eye is adjusted to the varying intensities of light

What is the duration of impressions on the eye? Is any thing known with certainty as to erect vision? On what principle does the stereoscope depend?

by the motions of the iris, which admits more or fewer rays according to its state of contraction, an action, on certain occasions, aided by the orbicularis palpebrarum, which, by bringing the eyelids together, limits the number of rays passing to the pupil.

Although many images may be simultaneously existing upon the retina, the mind possesses the power of singling any one of them out and fastening attention upon it, just as among a number of musical instruments simultaneously played, one, and that perhaps the feeblest, may be selected, and its notes exclusively followed. These phenomena, however, are not dependent upon any peculiarity of construction of any of the organs of sense; and as the mind can perceive the images of external things, so can it give rise to spectral illusions which may simulate perfectly the aspect of external forms. The anecdotes of such occurrences found among all people are not the fabrications commonly supposed. The mind can be readily deceived, even in spite of itself, as the phenomena of the stereoscope prove; and spectres, having their origin in natural or diseased conditions of the brain, may accurately replace images that have been painted in the eye. It is said, however, that we may readily distinguish, by means of a simple optical test, a true external apparition, if any exists, from a phantom of diseased imagination; for by pressing duly with the finger on the ball of one of the eyes, external objects are at once doubled, but it is not so with a mental illusion; and we may therefore suspect that, even in the best authenticated cases of the appearances of these unnatural forms, had this test been applied, their true character would have been ascertained; and that, since none of them would have undergone duplication, they would at once have been detected as mere hallucinations of the mind.

It is to be understood that the sensation of light is purely mental, and whatever can disturb the nutrition or waste of the retina will give rise to luminous impressions. The pressure of the finger on the ball of the eye, a blow, the passage of an electric current, and divers

What is the nature of ocular spectra and subjective images? What test is there for them? How is it known that the sensation of light is purely mental?

other causes, will at once produce the appearance of light, and even of colors. Heat is only one out of a multitude of agents that can disturb the retina.

3*d*. *Of the Accessory Apparatus of the Eye.*

The accessory apparatus of the eye consists chiefly of the eyebrows, the eyelids, the Meibomian glands, the lachrymal mechanism, and the muscles for the movement of the ball.

The eyebrows are two arches of integument, covered with hair, on the upper edge of the orbit. They are usually classed with the appendages of the eye upon the supposition that they protect that organ from undue intensity of light, or preserve it from the ingress of drops of sweat. They aid greatly in the expression of mental emotions, but perhaps should rather be looked upon as among the remaining vestiges of the hairy tegument affording a protection to the entire skin of other mammals below man in the animal series. The eyelids may be described as a pair of valves, the upper one having a much greater latitude of motion than the lower. Their use is to afford protection to the eye by closing entirely over it, more particularly during sleep; to keep its optical surface moist and free from dust by their winking motion. They are brought into action by the contact of air or of irritating particles, through the fibres of the fifth and facial nerves, or by the agency of light upon the retina. The edges of the lids are furnished with rows of curved hairs, the eyelashes, adding greatly to the protection of the delicate organ beneath, while permitting vision to take place to a certain extent. Opening upon the edges of the eyelids are the foramina of the Meibomian glands, in the upper lid there being about thirty, in the lower somewhat fewer. The glands themselves are imbedded on the internal surface of the cartilage of the lids, and afford an oily secretion, to discharge the double duty of preventing adhesion of the lids, and, by its relation of capillary attraction, hindering the overflow of the water which moistens the eye upon the cheek.

Of the lachrymal apparatus, it may be said that in the

Of what does the accessory apparatus of the eye consist? What is the use of the eyebrows? What is the use of the eyelids?

same manner that we breathe upon a spectacle glass and wipe it that its surface may be perfectly clean, so it is necessary for the optical action of the cornea that its surface should be constantly washed, and even more so, for its lamellated structure is such that, if it be not kept constantly damp, it loses much of its transparency. This therefore renders it necessary that there should be a mechanism for the supply of water, another for spreading that water uniformly over the surface of the cornea, and a waste-pipe for carrying any surplus away. The lachrymal gland discharges the first of these duties. It is situated in the upper and outer angle of the orbit; its secretion, a bitter and somewhat saline water, is brought to the surface of the conjunctiva by eight or ten little ducts arranged in a row for the purpose of equalizing their discharge. The spreading of this fluid over the eye, and the simultaneous wiping of the surface, is accomplished by the eyelids. Usually the water that has been employed is dissipated by evaporation into the air; but if, by reason of meteorological circumstances, such as the dampness of the atmosphere, or by the supply being too abundant, there should arise an excess, it is carried off through two minute orifices upon the edge of the eyelids, the puncta lachrymalia. These draw off any collection of water that may have accumulated in the lachrymal lake, and, carrying it into the lachrymal sac, discharge it through the nasal duct into the cavity of the nose. From this it is removed by evaporation, the current of air alternately introduced and expired affording the means of accomplishing that object in a remarkable manner. But should the discharge of water from the lachrymal gland become excessive, as in weeping, this draining mechanism is insufficient, and the water is discharged as tears down the cheek.

Describe the lachrymal apparatus. In what manner does it operate?

CHAPTER XVII.

OF TOUCH.

Functions of the tactile Mechanism: its Structure.—Regions of different Sensitiveness.—Perception of Temperature.

THE tactile organ is the skin, or some part, modification, or appendage of it. The general functions of the skin have been already described. It remains to speak of it in connection with the sense of touch.

In man, the skin possesses tactility to a different degree in different regions. On the tips of the fingers and on the lips the sensory perception is most acute, while it is at a minimum on the trunk and thigh. Its proper organ is to be regarded as arising from a concentration of general sensibility of the skin upon a special construction, the papillary body, as it is termed. The organs of vision and hearing consist essentially of two portions, a receiving and a nervous, the former being constructed on the principles of optics in the one case, and of acoustics in the other. A similar doubleness of structure may be recognized in the instance now before us, though with a difference of effect, for in those cases the outer or receiving organ is for the purpose of more powerfully concentrating the influence received, but in touch it is the reverse. The office of the cuticle, which covers over the true skin, is to render it less sensitive to external impressions, and for this reason, therefore, it varies in thickness in different regions, being less developed on those portions that are more particularly devoted to tactile sensibility. Considering the hand, or, perhaps, more correctly, the tips of the fingers, as being chiefly devoted to the purposes of touch, no construction could be conceived of better adapted to that end. Placed at the extremity of the arm, a lever jointed at its middle, the

Does the skin possess equal tactility in all its parts? What is the function of the papillary body? What doubleness of structure may be observed in the skin? Describe the general construction of the organ of prehension.

elbow, and the fore part of which has a motion of partial rotation, pronation, and supination upon its own axis, the hand being carried so that its palm presents upward or downward, or in any of the intermediate positions included in the half-circular motion—jointed again by the bones of the wrist, so as to obtain a hinge-like movement, the hand may be flexed or extended almost 180 degrees upon the forearm. Its bony structure, subdivided into suitable pieces, is clothed with a multitude of muscles or their tendons. In the fingers and thumb the structure breaks up into five separate pieces, possessed of an incredible firmness when we consider the numberless motions accomplished. The position and articulation of the thumb, enabling it to set itself in opposition to the other four digits, a feature constituting a hand, properly speaking, gives the power of grasping things perfectly, and makes the whole organ a perfect mechanism of prehension. The papillary structure, developed in its utmost refinement on the tips of the fingers, and fortified behind by the nails, which present moderate resistance to pressures, completes this contrivance. There have been authors who have asserted that the superiority of man over other animals may be entirely accounted for by his possession of a hand—a statement which, though it can not be maintained in its generality, is yet a very good proof of the appreciation in which this wonderful instrument is held by those who have studied its construction and functions most closely.

Between the indications that have to be dealt with by the hand as an organ of touch, and those dealt with by the eye, there is an essential difference. The eye, for example, receives the pictures of external objects upon a surface, but the hand examines the solidity of bodies. The former is occupied with length and breadth; the latter with all three dimensions, length, breadth, and thickness conjointly.

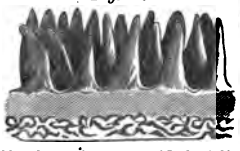
The mechanism for touch, as distinguished from the general dermoid sensibility, is the papillæ. They may be described as conical eminences on the cutis, at once

What is the essential construction of the hand? In what respect is there a difference between touch and sight? Describe the structure of the papillæ.

solid and flexible, sometimes clavate in form, and sometimes having numerous points. They are about the $\frac{1}{100}$ of an inch in height, and the $\frac{1}{250}$ of an inch in diameter at their base, these dimensions varying, however, very greatly with the situation. They contain a loop of blood-vessels and a twig of a sensory nerve, for all the centripetal nerves, with the exception of those devoted to the special senses, may be regarded as concerned in this function. The papillæ contain an elastic substance—axile body, as it is termed—serving to heighten the sense, and the yielding structure of the skin aids in the same effect. The papillæ are covered over with the cuticle, through which, therefore, all action on them must take place.

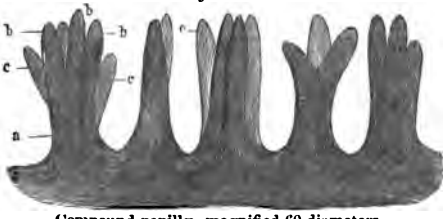
Fig. 94 represents simple papillæ of the palm, the cuticle having been detached. *Fig.* 95, compound papillæ, with two, three, or four points: *a*, base of a papilla; *b b b*, separate processes; *c c c*, processes of papillæ whose bases are not visible.

Fig. 94.



Simple papillæ, magnified 35 diameters.

Fig. 95.



Compound papillæ, magnified 60 diameters.

The mode in which the nerve fibre terminates in the papilla is as yet doubtful, some asserting that it is arranged as a returning loop, and some that it is by a pointed extremity.

The sensitiveness of a part is in proportion to the number of papillæ it contains. Tables have been constructed setting forth the relations of different regions, as determined by placing a pair of compasses, the points of which were covered with cork, on the parts to be tried, the eyes being shut, and closing the compasses until the pieces of cork could no longer be distinguished as separate. It appears that this will take place on the tip of the tongue when the points are the $\frac{1}{24}$ of an inch apart;

How may the sensitiveness of a part be measured?

on the tip of the third phalanx, at the $\frac{1}{12}$ of an inch; on the lips, the one sixth of an inch; tip of the great toe, half an inch; the lower part of the occiput, 1 inch; and on the middle of the thigh, $2\frac{1}{2}$ inches.

Our estimates of the hardness and softness, roughness and smoothness of bodies, is primarily dependent on indications derived from the sense of touch. We should make a distinction, however, between feeling and touching, the former being essentially passive, the latter active; and though we usually suppose that, of all our senses, touch is the most reliable, it often conveys to the mind illusory impressions, as, for instance, in the well-known experiment of Aristotle, when the tips of the fingers are crossed over each other, and a pea rolled beneath them, it seems as if there were two peas, one under each finger. The indications of touch are generally more correct than those of feeling. Thus, if we close our eyes, and another person moves the tip of our finger over an unknown surface, he can completely deceive us by duly varying the pressure, and make us believe that it is concave or convex, whereas it may be flat; but if we pass our fingers over the surface ourselves, we very quickly come to a true conclusion, because now we are conscious of the exertion of muscular power; and from what has been said respecting hearing, we may infer how delicate our estimate of muscular exertion is. The former is therefore an example of feeling, the latter of touch.

Connected with this distinction are the singular phenomena of tickling; the regions most readily affected by this are those of low tactile sensibility. A person can not tickle himself, though it is said that cases are upon record in which one has been tickled to death by another.

Besides affording an estimate of external pressures, the sensory organ enables us to discover variations of temperature. It may therefore be thus effected by bodies upon contact or by bodies at a distance; and though we usually confound the two indications together, there is, in reality, a distinction between them; thus, in certain conditions of paralysis, the indications of the con-

What is the distinction between feeling and touching? What is Aristotle's experiment?

tact of bodies may remain, but those of heat and cold may have totally disappeared. On examining a surface from which the skin has been removed, it does not appear capable of distinguishing hot from cold bodies, but only communicates to the mind an indefinite sensation of pain; nor can we create sensations of heat or cold by any irritation of the nerves. The measure of temperature by the agency of the skin is very far from being exact, as is proved by the simple experiment of dipping the finger into very warm water, and then the whole hand into water many degrees cooler. The increased extent of surface seems to overcompensate for the lower temperature, and we come to the erroneous conclusion that the cooler specimen is the warmer of the two samples.

As sounds may be heard which have no reality, but merely originate in the brain, or spectral illusions may be seen, so the sense of touch is subject to similar hallucinations, as a sensation of pressure or weight, or the crawling of insects on the skin; and though we can not, by artificial irritation of the nerves, give rise to impressions of heat and cold, those effects very frequently occur in this interior or subjective way.

CHAPTER XVIII.

OF SMELLING.

Structure of the Organ of Smell.—Its proper Instrument the First Pair of Nerves.—Limited Region of Smell.—Duration of Odors.—Subjective Odors.

By the sense of smell we are able to distinguish many gaseous and vaporous substances from one another. They enter the nostrils with the respiratory current, and are brought in contact with the olfactory or Schneiderian membrane. Though received at first in the elastic state, they become dissolved in the mucus moistening that membrane. It does not follow, however, that all vapor-

Is the measure of temperature by the skin correct? Can subjective sensations of touch occur? What is the mode of action of odors?

ous substances give rise to the perception of an odor; for example, water itself communicates no sensation whatever.

The general principle involved in the construction of the organ of smell is to expose an extensive and constantly moistened surface to the air brought in by the respiratory current. Of course, other things being equal, the larger the surface, the more perfect the sense. The object of gaining a great extent of superficial exposure under a relatively small volume is accomplished by spreading the sensitive mucous membrane on projections or shelves, which also serve the purpose of intercepting the incoming current of air.

The nose, thus constituting the commencement of the respiratory tract, forms a characteristic feature of the countenance. It is composed in part of bones and in part of cartilages, covered over with muscles and integument. Its five cartilages give to it shape in its inferior portion, and, by their elasticity, enable it to resist external injury. The whole surface of the nasal cavities is covered over with mucous membrane, to which the names of pituitary or Schneiderian membrane have been given. This mucous membrane likewise extends into the maxillary antrum, ethmoid, and sphenoid cells, or sinuses adjacent, and opening into the same nasal cavity. The Schneiderian membrane is highly vascular, and receives its nervous supply from the nasal branches of the fifth pair, which give it common sensibility, but its olfactory function depends on the distribution a certain portion of it receives from the first, or olfactory nerve.

Fig. 96. *Fig.* 97.



Fig. 96 illustrates the distribution of the olfactory nerve on the septum of the nose. *Fig.* 97 is its distribution on the outer wall of the nasal fossa.

That the function of the first pair of nerves is olfac-

What is the general principle of construction of the olfactory organ? Of what portions is the nose composed? What is the Schneiderian membrane? Which pair of nerves is the olfactory?

tory is proved by many facts. Animals in which these nerves have been divided are no longer affected by odors of any kind, and, generally speaking, the greater the development of these nerves, the acuter is the sense of smell. In persons in whom this sense has been defective or totally absent, or in those who have been troubled with unpleasant odors of a subjective kind, post-mortem examinations have shown a corresponding absence or lesion of these nerves.

In man, the proper olfactory organ is formed by the distribution of the olfactory, or first pair of nerves, on the mucous membrane covering the upper part of the nose, the internal set of filaments being disposed on that of the septum, the external on that of the superior and middle spongy bones. The membrane is very vascular, and covered with a thick, pulpy epithelium. The filaments distributed to it have lost the white substance of Schwann. It is those parts alone to which these filaments are distributed which possess the sense of smell. It seems to be necessary for the vaporous or gaseous substances to be dissolved in the moisture covering the olfactory membrane in order to their exerting a proper effect. If, by chance, the membrane be too dry, the sense of smell is temporarily lost, and the same likewise occurs if it be unusually moist.

From the mode of distribution of the olfactory nerve, it follows that the sense of smelling is restricted to the upper portion of the nasal cavity; and, for this reason, when we desire to detect odors with unusual precision, the air is drawn violently into that region by sniffing. On the contrary, we avoid the perception of odors by breathing through the mouth, or, as the common phrase is, by holding the nose.

In one respect there is a striking difference between this sense and vision and hearing. We can perceive many luminous impressions at the same time, or hear many sounds in rapid succession; but not so with odors. We can smell only one thing at a time, or, at all events, the impression remains long upon the olfactory apparatus, perhaps because the odoriferous substance remains

How are the olfactory nerves distributed? To what portion of the nasal cavity is the sense of smell restricted? What is the cause of the duration of odors?

dissolved in the attached moisture. The identification of substances by their odor necessarily implies a resort to recollection or memory, and sometimes we have to apply the fragrant object again and again to the nose before we can recall with satisfactory precision its name.

Diseases of the central organs will sometimes give rise to the perception of subjective odors, just as they do to spectral illusions or sounds in the ears.

CHAPTER XIX.

OF TASTE.

Conditions for Taste.— Structure and Functions of the Tongue.— Tactile and Gustative Regions of the Tongue.— Complementary Tastes.

THOUGH the function is participated in by other portions of the oral cavity, the tongue is to be regarded as the organ of taste. The physical conditions under which savors are perceived is that the substance shall be presented in solution in water, or, at all events, in the saliva. From vision, hearing, and smell, the sense of taste differs in the circumstance that it requires the contact of the acting body.

Sensations of taste are very frequently conjoined with olfactory perceptions, so that we mistake the one for the other. There are many substances, reputed to have a powerful flavor, which become tasteless when the nose is held; and this remark applies more particularly to such as are at the same time volatile and soluble in water.

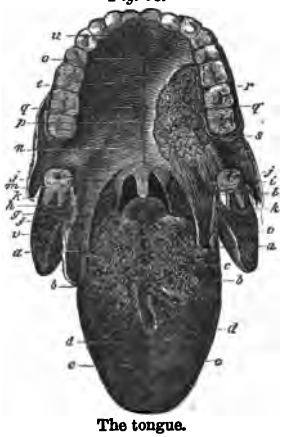
The idea of taste may arise irrespectively of the presence of any actual substance. A sharp blow will produce it, as also the passage of a feeble voltaic current. A narrow jet of air directed upon the tongue causes a taste resembling that of saltpetre. If the tongue be dry and parched, its power of discriminating tastes is greatly enfeebled, and the same thing takes place if its temperature is very much changed, either by elevation or depres-

Can subjective odors occur? What is the physical condition for the perception of tastes? How may that be related to the perception of odors? Give instances of the production of tastes by incidental agents.

sion, as by keeping it for a short time in contact with hot or very cold water.

The action of the tongue, as the organ of taste, depends upon the papillæ on its surface. These structures give to the upper portion of the tongue its rough appearance. They are of three kinds: 1st. The conical papillæ, which are the most numerous; 2d. The circumvallate papillæ, situate near the base of the organ, and from $\frac{1}{20}$ to $\frac{1}{12}$ of an inch in diameter, with a crater-like depression, round the edge of which is a groove, and again a circular elevation; 3d. The fungiform papillæ, which are chiefly on the sides and tip, their shape being conical, the narrow end of the cone being downward. The epithelium of the tongue is less dense over the fungiform papillæ, and hence their projecting appearance: it is more dense over the conical papillæ, and projects from them in processes presenting an aspect like that of hairs. Some of them contain hair-tubes. Besides these, the surface of the tongue has a papillary structure resembling that of the skin—secondary papillæ, as they are termed. It is supposed that the conical papillæ are chiefly organs of prehension; the others are organs of taste, but that function is participated in by other portions of the surface of the mouth, as, for example, the soft palate, its arches, and the tonsils.

Fig. 98.



The tongue.

Fig. 98 represents the surface of the tongue and the adjacent parts: *a a*, lingual papillæ; *b b*, circumvallate papillæ, disposed along two converging lines forming the lingual V; *c*, foramen cæcum; *d d*, fungiform papillæ; *e e*, filiform papillæ; *f*, frænum epiglottidis; *g*, epiglottis; *h*, anterior pillar of velum; *i*, stylo-glossus; *l*, isthmus of the fauces; *m*, uvula; *n*, velum pendulum palati; *o*, hard palate; *p*, raphe; *q q*, orifices of the excretory ducts

How many kinds of papillæ has the tongue? Describe *Fig.* 98.

of the palatine glands; *r*, palatine glands, the mucous membrane being removed; *s*, palatine glandules; *t*, mucous membrane covering the same glands; *u*, palatine tubercle; *v v*, section of the lower jaw.

The organ of taste is placed at the commencement of the digestive canal; hence the characters of substances may be examined with deliberation while they are yet under the control of the will, for when once a body has entered the œsophagus it is swallowed involuntarily. The tongue, therefore, gives warning of the presence of deleterious substances, and in no small degree excites the appetite by receiving the impression of pleasant flavors. The essential condition under which it acts is a moist state of its surface, for the dry tongue, though it enjoys common sensibility, after the manner of any portion of the external tegument, does not enjoy taste. One of the duties of the salivary glands is incidentally to maintain this moistened condition. To a certain degree, taste may be regarded as a refinement on touch.

The surface of the tongue presents the tactile and gustative powers in an inverse manner. Examined by the method described in the chapter on touch, the compasses must be opened to a great extent, as we pass from the tip toward the back of the tongue, in order that a double impression may be perceived. This condition appears to be in accordance with the requirements of the organ, common tactile sensibility being most necessary at its outer extremity, and this gradually passing off into the refinement of taste. The action of any given substance may be increased by motion and pressure, as when it is rolled over the tongue, or held thereby. Its sense of discrimination may be rendered more acute by education.

As with the organs of the other senses, so with this, an impression made upon it does not instantaneously cease, but remains for a certain period of time, indeed, in this instance longer than in those. Hence many substances acting in rapid succession give rise to a confused effect, though it is said that, out of such interminglings, an accomplished epicure can fasten his attention on one,

What are the uses of the sense of taste? Which are the tactile and which the gustative regions of the tongue? Is it possible to single out one taste from many others?

and continue to recognize it just as we recognize and follow the sound of one instrument in an orchestra. No explanation has as yet been given of the manner of action of different tastes, though it is asserted that some act upon one, and some upon another set of the papillæ. After-tastes are also observed, occasionally of a complementary kind, as, for instance, the intensely bitter taste of tannin is followed by a sweetness. These after effects modify the taste of substances taken while they last. They therefore form an ample subject for the profound contemplation of the epicure, and should occupy the serious attention of the cook. They may be illustrated in a general manner by the injurious effect of sweet substances upon the flavour of delicate wines.

CHAPTER XX.

OF ANIMAL MOTION.

Ciliary and Muscular Motion.—Description of Cilia. Muscular Fibre: its Forms, Non-striated and Striated. —Muscle Juice.—Manner of Contraction of a Muscle: its supply of Blood-vessels and Nerves.—Duration of Contractility.

Doctrine that Muscle Contraction is the result of Muscle Disintegration.—Manner in which ordinary Cohesion is brought into play.—Manner of Restoration.—Removal of the Heat and Oxidized Bodies.

Rigor Mortis.—Connection of Muscle for Locomotion. —Of Standing.—Walking.—Running.

Animal motion is of two different kinds: 1st. It is accomplished by vibrating cilia; 2d. By the contraction of cells arranged in the form of a fibre.

OF CILIARY MOTION.

The epithelial cells of the cylindrical and of the tesselated kind are occasionally arranged with delicate projecting striæ on their free extremities. The length of these varies from the $\frac{1}{500}$ to the $\frac{1}{10000}$ of an inch. These striæ are termed cilia, and the cells are said to be ciliated.

Give examples of complementary or after-tastes? Of how many kinds is animal motion? Describe cilia and their movements.

Examples are presented by the mucous membrane of the respiratory surface and of the nasal cavities; an illustration is given in *Fig.* 99. The cilia may be regarded as prolongations of the cell wall itself. They exhibit a vibrating motion back and forth, recalling the movements of stalks of grain in a field as the wind is passing over it, the ears bending down and rising again in the breeze, and throwing the whole surface into waves. The cilia also exhibit a movement like that known as the feathering of an oar, or sometimes as turning round upon the point of attachment, as upon a centre, giving rise to a sort of conical motion, the free end describing a circle. These motions seem to be perfectly involuntary, for they not only take place long after death, but even in detached portions, the ciliary cell being uninjured and entire. The seats of ciliary action are always moistened surfaces.

Fig. 99.



Ciliated cells.

Ciliary motion is independent of nervous agency. The control of temperature and of chemical reagents over it shows that it is of a physical nature.

Of Muscular Motion.

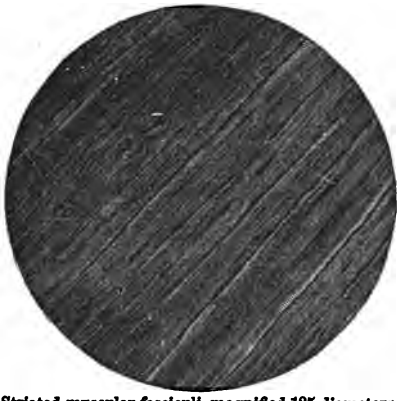
The muscular system consists of muscular fibres, tendons, bones, together with various accessory parts, such as ligaments, sheaths, bursæ mucosæ, synovial capsules, fascia. Its action depends on the primary fact that, under appropriate influences, muscular fibre shortens.

Each voluntary muscle consists of a collection of fasciculi, exhibiting the characteristic appearance of transverse striation, as in the photograph of muscular structure of the frog (*Fig.* 100). The primary fasciculi are collected into larger bundles, secondary muscular fasciculi, held together by connective tissue, and these, again, into still larger, the tertiary.

The primitive fasciculus is enveloped in a delicate sheath, the sarcolemma, as shown in *Fig.* 101, in which the fasciculus, though torn across, is held together by

How is ciliary motion known to be involuntary? How is it known to be of a physical nature? Of what does the muscular system consist? What is a muscular fasciculus? Into what larger bundles is it collected?

Fig. 100.



Striated muscular fasciculi, magnified 125 diameters.

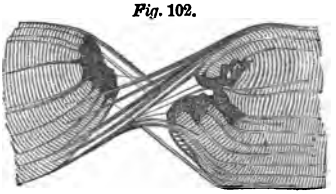
the sarcolemma. The specimen is from the human muscle. *Fig.* 102 is a good representation of the same fact. The sarcolemma is a delicate membrane, of great tenuity in man. Within the sarcolemma the primitive fasciculus is seen to be composed of many parallel fibrils, which may, by maceration or chemical agents, be separated from one another. These fibrils present a beaded aspect, and, since their constituent elements are arranged side by side in parallel planes, they give to the fasciculus the appearance of striation it presents. The longitudinal striation of the fasciculus arises from the fibrils themselves.

Fig. 101.



Human sarcolemma.

Fig. 102.

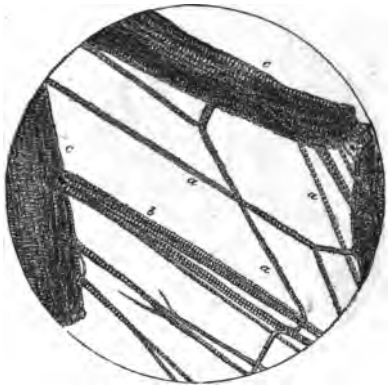


Sarcolemma of fish.

Fig. 103 (page 308) is a photograph of ultimate muscular fibre of the pig. The rectangular form of the

What is the sarcolemma? What is the appearance of striation in muscle fibre due to?

Fig. 103.



Ultimate muscular fibre, magnified 200 diameters.

constituent cells is well seen at *a a a*. At *b*, probably by reason of a twist, tension, or undue strain, a spiral appearance is presented; *c c* are the primitive fasciculi.

A fluid surrounds the fibres of striped muscles, and the fibre cells of smooth ones, which is wholly different from the plasma of the blood. It contains a large amount of casein.

It is commonly stated that muscular motion is accomplished by fibres of two different kinds: 1st. The simple, non-striated, unstriped, or organic fibre; 2d. The striated, striped, or voluntary fibre just described. Though this subdivision may be convenient, it can scarcely be regarded as accurate, since the former variety passes by insensible degrees during development into the latter, and cases, indeed, are not wanting in which the same fasciculus presents in different parts both conditions at once.

The non-striated muscular fibre, *Fig.* 104, consists of translucent bands of a soft granular material, varying from the $\frac{1}{2000}$ to $\frac{1}{5000}$ of an inch in breadth, and exhibiting here and there the traces of nuclei, particularly after the fibre has been acted on by acetic acid, as is shown in *Fig.* 105. Each fibre may be regarded as an arrange-

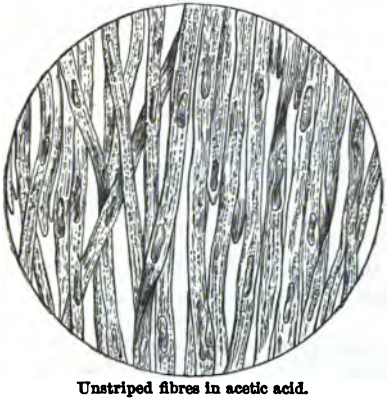
How many kinds of muscular fibre are there? Why is not this division strictly accurate? Describe the non-striated muscular fibre.

Fig. 104.



Unstriped fibres.

Fig. 105.



Unstriped fibres in acetic acid.

Fig. 106.



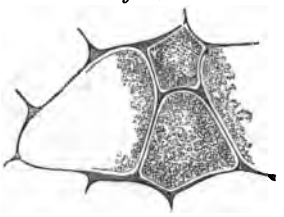
ment of nucleated cells, the nucleus being of a cylindroid or spindle form. The contractile content within is syntonin. Non-striated fibre is not usually attached to fixed points, as to bone, but, by being collected into parallel bundles, different bundles interlacing with one another, contractile planes or surfaces are formed, such as the cylindrical coat of muscular structure of the digest-

How may the nuclei of it be rendered apparent? How is it usually arranged?

ive tube, or the contractile layer of the urinary bladder. Similar fibres, imbedded in the skin and connective tissues, communicate to them the quality of corrugation or contractility. The fasciculi are bathed externally with an acid juice, characterized by containing salts of potash, phosphoric acid, creatine, and inosite. The general appearance of fibre cells of this class is given in *Fig.* 106 (page 309): *a* is from the small intestine of man; *b*, from the fibrous investment of the spleen of the dog.

The striated muscular fibre consists therefore of fasciculi, with an elastic investment of sarcolemma, collected into bundles. The contractile constituent is syntonin; and though the general rule is that the primitive bundles shall run isolatedly and parallel to each other, in certain cases they anastomose. In its ultimate construction, the form of fibre may be regarded as consisting of a series of cells, as shown in *Fig.* 103, the diameter of which varies according to the actual condition of the muscle, whether it is in the contracted or relaxed state, but it may be taken, on an average, at the $\frac{1}{10000}$ of an inch. The cells are placed end to end, the boundary walls upon the end presenting the appearance of a delicate transverse line. In length, muscular fasciculi vary from the sixth of an inch to two feet. The larger animals furnish some that are even much longer. The normal form is doubtless cylindrical, but this is constantly departed from, each accommodating itself to the pressure of the adjacent ones. The sarcolemma serves as a partition between its included fibrils and the capillary blood-vessels and nerves, which imbed themselves in the rounded angular spaces between adjacent bundles. The cross section of a portion of muscle shows the manner in which the sarcolemma and the fibres are arranged. *Fig.* 107 is from the human biceps.

Fig. 107.



Transverse section of human muscle.

It has already been stated, in connection with *Fig.* 104,

With what juice is it bathed? What is the contractile constituent of striated fibre? What is the diameter of its constituent cells? Of what length may such fibres be? How are the blood-vessels and nerves arranged?

that the striated form of muscular fibre derived its name from the circumstance that, when examined by a sufficiently high power, it appears to be crossed by delicate transverse lines, the longitudinal separations between the fibrils being also visible. This is seen in the specimen of insect muscle represented in the photograph, *Fig.* 108, and under a still higher magnifying power in

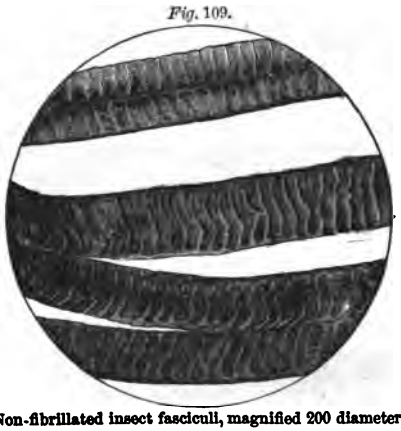
Fig. 108.



Non-fibrillated insect fasciculi, magnified 50 diameters.

that of *Fig.* 109. The distance between the transverse

Fig. 109.



Non-fibrillated insect fasciculi, magnified 200 diameters.

striæ varies with the condition of the muscle, but on an average it is represented as being about the $\frac{1}{3000}$ of an

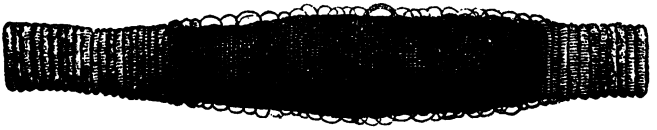
From what does striated muscle fibre derive its name? What is the average distance between its striæ?

inch. Many more striæ are crowded together when contraction takes place, and they retire from each other as soon as relaxation occurs.

It is said that the voluntary muscles contain in their muscle juice more acid than is enough to neutralize all the alkali of the blood. The electro-chemical relations of this interfascicular acid juice and the alkaline plasma of the blood are doubtless the cause of the production of those electric currents which have been demonstrated in the muscles. It does not follow, therefore, that these currents occur in the natural state: they may be the result of the experimental arrangement for their own detection, since it has long been known that an acid and an alkaline juice, separated from each other by a conducting organic body, will form an effective voltaic circle.

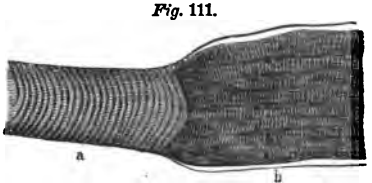
The contraction of a muscular fibre does not take place throughout its whole length at once; it generally begins at the end, a change of aspect arising from the approach of the opaque centres of the cells to one another, and this occurring simultaneously across the whole fibre. This approach may, however, ensue in different parts of the length at the same time, the sarcolemma being raised up in bullæ as the contraction takes place.

Fig. 110.



Contracting muscle of Dytiscus.

Fig. 111.



Fasciculus contracting.

This effect is shown in *Fig.* 110, in which the thickened portion of the contracted middle space of the muscle is surrounded with the sarcolemmic bullæ. *Fig.* 111 exhibits,

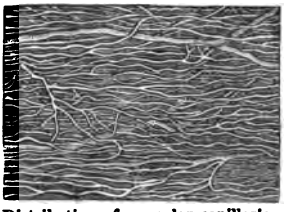
How may electric muscle currents be explained? In what manner does the contraction of a muscle take place? What happens to the sarcolemma?

under the same circumstances, a fasciculus from the eel, *a* being the uncontracted, *b* the contracted part, on the edge of which the sarcolemma is again raised up.

Different portions of the length of the fibre assume this condition at different moments, and hence the whole structure is thrown into a form recalling the motion of a worm. The zigzag appearance arises from the circumstance that when relaxation of the fibre occurs all its parts are not brought at once into the same state, but while some are contracted others are in the opposite condition. It is to this reciprocation of motion that the sound usually emitted while the muscle is in action, a low ringing sound, is to be attributed.

Striated muscle is often attached to bone, or other substance on which it has to exert its mechanical power, by intervening fibrous tissue constituting tendon. These fibres are collected in groups, so as to present primary, secondary, and tertiary fasciculi. The tendinous fibres are brought in relation with the sarcolemma, and thus form a sheath connected with adjacent ones by other detached fibres.

Fig. 112.



Distribution of muscular capillaries.

From the peculiar structure of muscular tissue, the capillary vessels distributed to it must run in a direction for the most part parallel to its fibres, as in *Fig.* 112.

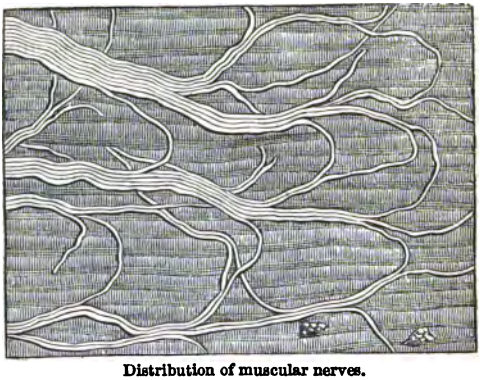
In the same general manner that the blood-vessels are distributed, so likewise are the nerves. An example of this is seen in *Fig.* 113, p. 314. They never penetrate the sarcolemma, but run in close contiguity with it, their distribution to different parts of the fasciculi being very unequal.

OF THE FUNCTION OF MUSCULAR FIBRE.

The mechanical action of muscular fibre depends on

Are all portions of the length of a fibre in contraction at once? Are adjacent fibres all simultaneously contracted? What is the cause of the sound a muscle emits? What is the mode of attachment of muscle to bone? In what manner is the distribution of blood-vessels and nerves to muscles arranged?

Fig. 113.



Distribution of muscular nerves.

the shortening of the long axis of the cells of which the fibres are composed. To this result the designation of contractility is given.

At one time it was supposed that the contraction of a muscular fibre depends so completely upon the agency of the nervous system that it might be considered as the direct function thereof; but a more critical examination of the circumstances of the shortening of the fibre cells shows that it possesses many features in common with the same contraction of the cells of plants, which have no nervous system. The influence passing along the nerve fibrils is only one out of many capable of causing muscular contraction. There is abundant evidence in support of the position that contractility is the result of the structure of the muscular fibre, and that it belongs to it, and is not a special function of nerves.

When muscular fibres are touched by a pointed instrument, they exhibit contraction even after they have been detached from the body, provided that too long a period of time has not elapsed. If it be of the striated variety, the bundle that has been disturbed alone contracts, and presently after relaxes; but there is no lateral spread or diffusion of the effect to adjacent bundles, except in the case of the heart, in which it would ap-

What is meant by contractility? How is it known that contractility does not depend on the nerves? What occurs when striated fibre is touched by a pointed instrument?

pear that the contraction of one part is diffused laterally, and a single disturbance is followed by many alternating contractions and relaxations, simulating, as it were, the normal function of the whole organ. But where the non-striated form is in like manner examined, the contraction takes place more slowly, spreads laterally to a wider extent, and is followed by a relaxation.

The capability of contracting continues in muscle fibre for a certain time after death, a period shorter as the rate of respiration is higher, and hence these effects were first observed by Galvani and others in the case of the frog and cold-blooded animals. Even after it has disappeared, it may be re-established by continuing the supply of arterial blood, as Dr. Brown-Sequard has shown: a fact illustrating in a striking manner the independence of the muscular contraction of the nervous system. Of course, as would have been expected, whatever interferes with due arterialization interferes with muscular power. This is the reason of the inability for exertion experienced in the thin air of mountain tops. The converse of this likewise holds good: the higher the rate of respiration, the more energetic the muscular power; and therefore, in birds, which respire most perfectly, muscular contractility is exhibited with the greatest energy.

The immediate cause of muscular contraction is to be sought for in the muscles themselves. So far from there being any thing mysterious or incomprehensible about it, as some writers insist, we probably shall not be very far from the truth if we assert that *muscular contraction is the necessary physical result of muscular disintegration.*

Reviewing the various conditions under which contraction occurs, destructive metamorphosis is the primary and leading one. Every thing seems to indicate that the contraction of a fibril can not take place without the loss of a part of its substance, and this ensues

What occurs when the non-striated kind is used? In what class of animals does contractility continue longest after death? How may it be restored? What effect have rarefied and condensed air on contraction? What is the cause of muscular contraction? Can a fibril contract without loss of weight?

even in the artificial motions that are established by electric currents in amputated muscles.

I therefore regard disintegration of the muscular structure as the primitive act, so far as the fibril itself is concerned, and contraction as the necessary consequence, that disintegration being brought about by the oxidizing agency of arterial blood. It must, however, be borne in mind that this waste is masked by its incessant repair, and that its condition at any moment of its action represents the actual balancing at that instant of the waste and repair respectively; and since the repair does not proceed with the same rapidity as the destruction, it needs must follow that, sooner or later, a point will be arrived at when there is an absolute necessity for repose to give to the renovating processes the opportunity or time for effecting a complete restoration.

It is probable that one cause of cessation of muscular contraction in any one point of a fibre is the momentary accumulation of wasted material, as might be illustrated in a coarse manner by the difficulty of causing a fire to continue burning when the ashes are permitted to accumulate, and the necessity of their removal before the combustion can go on. Two separate events have to occur before a fibril that has been in contraction is ready to contract again: these are the removal of the oxidized products, and the renovation of the interior of the cells. The two probably go on coincidently, the veins taking one part of the duty, and the arterial capillaries the other.

In non-striated muscular fibre, in which the supply of blood-vessels is much less copious, there is a possibility for a lateral propagation of effect, because of the possibility of the lateral propagation of the heat, either supplied directly from the nerve tubule or arising from the oxidation going on. The sluggishness of its first contraction, the longer continuance, the propagation from fibre to fibre laterally until the effect wears out or is reenforced by some new stimulus, might almost seem to

In contraction what is the primitive act? How is the disintegration brought about? How is it that the state of the muscle may be said to be masked? What is probably the cause of the local cessation of contraction? What are the peculiarities of non-striated fibre contraction?

be the necessary result of the imperfect supply of arterial blood, the sluggish removal of the products of waste, and the more perfect opportunity for the diffusion of heat. This doctrine therefore meets with a very happy illustration in the phenomenon displayed by the contraction of the two kinds of fibre.

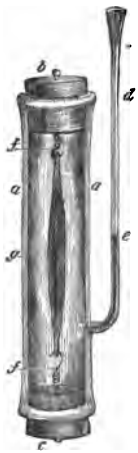
But the question returns upon us. Admitting the descriptions that have now been given to be a true representation of the facts, and also of their natural sequence, what is the actual physical cause of the shortening of the muscular fibril?

It is capable of demonstration that muscular contraction ensues as the direct consequence of destruction of muscular substance, and that a great linear extent of movement may be accomplished by the removal of an insignificant amount of substance. If 100,000 fibrils lost one third of their entire substance—a thing which, of course, could scarcely take place—the diminution of weight would only amount to a single grain. Our conception of this action may perhaps be rendered clearer by an illustration. If we had an iron thread of excessive tenuity, composed, for instance, of a single row of iron atoms set end to end, and could, by suitable processes, effect the removal, here and there, of atoms in the line, an instantaneous contraction would be the result, the thread shortening in proportion to the number of atoms removed, but shortening with an energy commensurate with the cohesive force of the iron itself, and yet ready to return to its original length the moment that fresh iron atoms present themselves to be introduced in the place of the abstracted ones; and so with muscular fibre, the molecular force of cohesion developed here and there by the removal of tissue is to be measured only by the cohesion of the fibre, though the loss of material which may have been the cause of that force coming into play may be very small indeed; nor does the quickness of relaxation present any difficulty when we consider the rapidity with which interstitial nutrition takes place, and the small quantity of matter to be supplied.

How are those peculiarities accounted for? What is the physical cause of the shortening of muscular fibril? How may this effect be illustrated?

I can not at this point avoid offering a criticism on the experiments by which it has been attempted to prove that a muscle, when it contracts, loses none of its bulk; the loss that does in reality occur is, it is true, very minute, perhaps so minute that, in the coarse apparatus resorted to in these experiments, it would be altogether inappreciable. Such a contrivance is represented in *Fig.* 114, in which *a a* is a wide tube for containing the muscle, *g;* it is also to be filled with water, and from its side a narrow tube, *d*, projects, the water reaching to some such point as *e*. The tube, *a a*, being closed at both its extremities water-tight by means of corks, *b c*, whenever the muscle is made to contract by an electric current, applied by means of the spring wires, *f f*, or otherwise, if enlargement occurred the water would rise at *e*, and if diminution it would descend; but as, upon trial, it is found that no movement whatever takes place, it has been inferred that the volume of the muscle remains unchanged. But no compensation whatever for temperature is provided! Yet it is positively known that when a muscle contracts it becomes warm, and, doubtless, these instruments, if delicate enough, would have led to the preposterous conclusion that a muscle after contraction is larger than it was before. But, even setting disturbances of temperature aside, such experiments are of no kind of value, since they contain no provision for the removal of the wasted material of the muscle, which still continues a part thereof, though it has become, to all intents and purposes, extraneous, and would, if in the living system, have been instantly removed by the veins.

Fig. 114.



Volume of contracting muscle.

Connected with the foregoing phenomena is that general rigidity of the muscles which occurs a certain time after death, and hence known as rigor mortis. This usually commences in the lower jaw and neck, invading

Describe the experiment illustrated in *Fig.* 114. What obvious objections is it liable to? What is meant by the rigor mortis? In what order are the muscles usually affected by it?

next the upper extremities, and reaching eventually the lower ones. After continuing for a period longer in proportion to the lateness of its beginning, relaxation ensues, the parts being affected in the same order as they were made rigid. The rigor mortis sometimes begins as soon as ten minutes after death, sometimes it is postponed as long as seven hours. In those who have died of chronic diseases it occurs and ceases very quickly. Both classes of muscles, striped and unstriped, are effected by it, and when it is over they present an unresisting and lax condition, and putrefactive change presently sets in. Even after cadaveric rigidity has been assumed, the contractile power of muscles may be restored by furnishing them, through a suitable arrangement, arterial blood; for this fact we are indebted to Dr. Brown-Sequard, his experiments having been made both upon man and animals. The arterial blood employed assumed, during its passage through the limb which was the subject of the trial, the venous character, and issued of a dark color. This restoration of contractility was by no means imperfect or transient; in one instance it continued for two hours.

By means of tendon the muscles are attached to the skeleton, which constitutes the solid framework of the system. Operating thus through the skeleton, the muscles are enabled to keep the entire body in the erect or standing position, and also to give it locomotion.

In man, the power of standing implies the conservation of the line of direction of the whole body within the narrow basis covered by the feet and between them. The head is balanced on the atlas so nearly under its centre of gravity that no ligamentum nuchæ is required, as in the case of other animals, to prevent it from falling forward. Nevertheless, a forward motion can be executed, amounting to about 75 degrees from the perpendicular, and a lateral motion right and left of from 45 to 50 degrees. In standing, the weight of the entire body is transmitted perpendicularly to the feet. These rest on the heel and the fore ends of the metatarsal bones, especially of the great and little toes, and on the points of the toes. The general centre of gravity of the entire body is a little above the transverse axis connecting the

By what artificial process may rigor mortis be counteracted? Describe the condition of standing.

heads of the thigh bones, and for equilibrium to be maintained, a perpendicular line drawn from this centre must always fall within the basis inclosed by the contour of the feet.

Even in the most perfect condition of rest that we can assume while maintaining the standing position, a great many separate muscular acts are necessarily required. Apart from those little voluntary changes incessantly occurring, the rhythmic action of the muscles involved in respiration, especially those of the abdominal walls, is perpetually changing the position of the centre of gravity, and therefore those muscles employed in keeping the spine erect are obliged to assume an antagonizing rhythmic action. This is at once the reason of the fatigue we experience in long standing, and of the difficulty infants encounter in their attempts to maintain the erect position.

In walking, the legs act like a pair of pendulums. The head of the thigh bone, which is their centre of motion, is held in its socket, not by muscular exertion, nor by its ligamentous arrangements, but by the pressure of the air, a fact that may be proved by very simple experiments. If the pressure of the air be removed, as in an exhausted receiver, spontaneous dislocation ensues. The trunk of the body is like a rod balanced on an axis passing through the hip joints, and advancing with the movement of the legs like a rod balanced on the tip of the finger. It is inclined forward or backward in correspondence with the motion or with the resistance of the wind; if the wind blows in front, we lean forward; if behind, we lean backward; the angle of inclination being in proportion to its force. In walking there are two distinct periods: the body is first poised on one of the limbs, and then rests for a moment on both. The advancing limb swings like a pendulum, bending at the knee so as to be shortened one ninth; the other straightening at the knee and hip joint, and so pushing the pelvis and trunk forward to be received on the limb that has just advanced. It is only in slow walking that the whole arc of motion is swung through, the time occupied being two thirds

What is the cause of the fatigue experienced? How is the head of the thigh bone held in its socket? What are the movements in the act of walking?

of a second. In quick walking and running only half a vibration is accomplished, and this in half a second of time. In slow walking each foot rests upon the ground one third of a second. The longest step made is half the entire span of the two extremities. To prevent swaying from side to side, the arms swing with the legs.

In running there is a moment when both feet are off the ground at once, and the body actually projected into the air. In walking there is a moment when both feet are on the ground together, the one not being raised till the other is planted. In running the steps are, on an average, twice as long as in walking; and the number of steps made in a given time in running and walking respectively is as 3 to 2.

CHAPTER XXI.

OF THE VOICE.

Origin of the Voice.— Comparative Physiology of Noise, Song, Voice.—Distinction between Song and Speech.—The Larynx, and its Action in Singing.— Speaking Animals and Machines.

For the production of the sounds necessary for intercommunication among the higher animals, and particularly for the speech of man, it might be supposed that some complicated and elaborate contrivance must needs be resorted to. This object is, however, accomplished by merely employing, on its escape from the system, the wasted product of respiration, the breath, which, as it issues outward through the respiratory passages, sets in motion a simple mechanism, and thereby originates all the exquisite modulations of song, and all the impressive utterances of speech. Is it not admirable that thus, out of dead and dismissed matter, results of so high an order, materially and mentally, are obtained?

What might be termed the comparative physiology of the voice is very simple. It appears first in invertebrate animals as a monotonous noise or cry, which gradually, in higher tribes, becomes more varied in loudness

What are those in the act of running? From what does the voice arise? Describe the comparative physiology of the voice.

and note. In the different stages of his existence man himself furnishes an illustration of this course. Voiceless before birth, with a piteous or monotonous cry in early infancy, articulate speech and song are the result of education, and through these the power is eventually gained of expressing the most refined emotions and the most elevated ideas. The solitary bell-like sound which the nudibranchiate gasteropods emit, thus produces, by its successive improvements, a wonderful result at last.

Among insects the modes of producing sounds are very various, some effecting it by percussion, some by the friction of horny organs. In others, the extremity of the trachea, through which the air escapes, is accommodated with vibrating membranes. The contractions of the muscles of the wings, brought vigorously into action during flying, occasion an alternate pressure and relaxation upon the tracheal tubes. The air, thus passing in and out, throws into vibration the valves of the spiracle, which, as seen in *Fig.* 115, are suspended upon a

Fig. 115.



Spiracle of insect.

dozen or more flexible supports; but their free edges, approaching within a certain distance of each other, are thrown into quick vibration by the passing current, in the same manner as is the vibrating spring of the accordeon. These vibrating plates of insects are the ru-

How are sounds produced by insects? Describe *Fig.* 115.

diments of the perfect vocal apparatus in man. Again, in others, the swiftly-recurring beating of the wings produces a sound, as, for example, in the musquito. Among vertebrated animals, those that breathe the air are vocal, nearly all fishes being mute. From fishes, as we pass upward, the sound and the instrument making it increase together in complexity. Through a simple chink, the air expelled from the respiratory sacs of snakes, by the contraction of their abdominal muscles, issues forth as a mere hiss, the sound being increased in the frog by the development of resonant cavities. From such simple noises we are conducted to the musical notes of birds, some of them being of exquisite purity and sweetness. In these, the vocal glottis is situated at the bifurcation of the trachea, another glottis being above for the final escape of the air. These vertebrated animals first introduce us to the mechanism for articulate speech, the raven and parrot being able to pronounce words with distinctness. The articulation is effected, as in man, by the motions of the tongue and other portions of the mouth.

For the farther consideration of this subject, it is necessary to understand that there is a distinction between song and speech. Song is produced by the glottis, speech by the mouth; or, perhaps, a more correct statement would be, that the larynx is the organ of song, the mouth of that form of speech called whispering, and for which nothing is required but a stream of air issuing from the fauces, the tongue and other organs giving it articulation; but for audible speech, a noise is created in the larynx, and modified by articulation in the mouth.

The double larynx of birds is replaced by a single larynx in man, serving at the same time for the entrance and exit of air, and likewise for vocalization. Birds having no lower larynx are voiceless. A general idea of the construction of the organ of voice in man may be gathered by supposing it to be composed of three portions, the trachea, the larynx, and the mouth. The trachea is the tube by which air is brought from the lungs

How are sounds produced by reptiles? How are articulate sounds produced by certain birds? In what manner are speech and song respectively produced? What is the construction of the human larynx?

and delivered into the larynx, a superposed structure, arranged upon the cricoid cartilage, on which is articulated the thyroid cartilage by its lower horns, around which a certain degree of rotation can be accomplished, so that the front of the thyroid may be elevated or depressed with a kind of bowing motion. Posteriorly, on the cricoid cartilage are placed the arytenoid cartilages, which can be approached or separated from each other, and from their summits pass to the front of the thyroid cartilage the inferior laryngeal ligaments or vocal cords. These constitute the essential organ of sound. The thyroid cartilage, by its motions, can determine the strain put upon them, and the arytenoids can either bring them into parallelism, or place them at an acute angle. The chink or fissure between them is the rima glottidis: its figure and width vary with the recession or approximation of the vocal cords, which, as the air passes by them, are thrown into vibration in the same manner as the reed in musical instruments. The epiglottis cartilage, which is above, guards the passage, and may also be supposed, by its descent, to deaden the sounds.

The slowness or rapidity of the vibration is dependent on the stretch of the vocal cords. The manner in which various degrees of tension can be given to the cords is readily understood by considering their attachments. In front, as we have said, they are fastened to the thyroid cartilage, posteriorly to the arytenoids. When the thyroid cartilage executes a bowing motion forward, the vocal cords are put upon the stretch, and similar variations of their tension and also of their position can be given by the movements of the arytenoid cartilages behind. When the air is moving in and out without giving rise to any sound, the chink of the glottis is angular, its point being forward, and from that the cords diverge posteriorly. For the production of sound, the cords must be brought parallel, or even inclining toward each other. If they incline away from each other, no sound will be produced. The pitch of the note will be determined by the stretch of the cords, and this, in its turn, will be determined by the contraction of the vocal muscles. The crico-thyroid and sterno-thyroid bow the

How are the vocal cords regulated? In what position must the cords be to produce sound?

front of the thyroid cartilage down, the thyro-arytenoid and thyro-hyoid carry it back; the former therefore stretch the cords, and the latter relax them. The opening of the glottis is likewise determined by other muscles, the posterior crico-arytenoid dilating it, and the lateral crico-arytenoid and the transverse arytenoid closing it.

Fig. 116 is the larynx, seen in profile: *a a*, half of the hyoid bone; *b*, thyroid cartilage, cut; *c*, thyro-hyoid membrane; *d*, cricoid cartilage; *e*, trachea; *f*, œsophagus; *g*, epiglottis; *h*, great horn of the thyroid cartilage, united to *i*, the great horn of the os hyoides, by *k*, the lateral thyro-hyoid ligament; *l*, thyro-hyoid membrane, traversed by the superior laryngeal nerve; *m*, posterior crico-arytenoid muscle; *n*, lateral crico-arytenoid; 1, inferior laryngeal nerve; 2, posterior crico-arytenoid twigs; 3, lateral crico-arytenoid twigs; 4, thyro-arytenoid twigs; 5, arytenoid twig.

Fig. 116.



Profile of larynx.

Fig. 117 is the posterior view of the larynx: *a*, base of the tongue; *b*, posterior border of the thyroid cartilage; *c c*, thyroid body; *d*, posterior crico-arytenoid muscle; *e*, arytenoid muscle; 1 1, superior laryngeal, traversing the superior thyro-hyoid membrane, and giving off lingual and epiglottic branches, and others to the mucous membrane covering the posterior face of the larynx; 2, twig for the arytenoid muscle; 3, anastomotic of Galien; 4, inferior laryngeal; 5, tracheal branches; 6, twig for the posterior crico-arytenoid muscle; 7, twig for the arytenoid muscle; 8, branch for the lateral crico-arytenoid and posterior crico-arytenoid muscles.

Fig. 117.



Posterior view of larynx.

The larynx is essentially a reed instrument with a double membranous tongue. That the rima glottidis is the seat of the origin of the sound is proved by the fact

Describe *Figs.* 116, 117. To what class of instruments does the larynx belong? How may it be proved that the rima glottidis is the seat of sound?

that when an aperture exists in the trachea below the glottis the voice disappears, but if above the glottis there is no effect. Moreover, the human or animal larynx can be made to produce its characteristic sounds with more or less distinctness, after it has been removed from the body, by directing a current of air through the trachea. Cases have occurred which have afforded the opportunity of observing the condition of the glottis while emitting sounds. The vocal cords are brought into parallelism with one another, and separated by an interval of scarcely more than from the $\frac{1}{100}$ to the $\frac{1}{150}$ of an inch; but when the air is moving in and out silently, the fissure assumes a divergent or triangular form.

An artificial larynx will give rise to sounds analogous to those of the human larynx. Such have been made of leather, and, better still, of caoutchouc.

The narrower the glottis is made, and the more tightly the cords are strained, the more rapidly they will vibrate, and the higher will be the musical note emitted. In an individual the range of the voice is rarely three octaves, but the male and female voice, taken together, may be considered as reaching to four. Generally, the lowest female note is about an octave higher than the lowest male, a similar remark applying to their highest notes respectively.

While thus song is laryngeal, speech, which is a modification thereof, is oral, or produced by the mouth. Man is not alone endowed with the faculty of uttering articulate sounds: several other animals, by education, may be taught to express them. Ingenious mechanics have also repeatedly invented speaking instruments, upon the same principle as that of the vocal organs, of combining the sounds of letters into words, and even into sentences, a convincing proof not only of the mechanical nature of articulate sounds, but also of the perfect manner in which the natural mechanism is understood. Animals which have been taught to speak may also be regarded as automata, for they have no comprehension of what it is they are uttering, and never produce articulate combinations spontaneously, but only as the result of instruction.

How near are the vocal cords to each other in the act of producing sound? What is the effect of narrowing the glottis? What is the range of the male and female voice? On what principle have speaking machines been made?

CHAPTER XXII.

OF THE ORGANIC CELL: ITS DEVELOPMENT AND REPRODUCTION.

Simple and Nucleated Cells.—The Simple Cell: its Parts and Functions. — The Nucleated Cell: its Parts and Functions.—Activity of the Nucleus.—Other Forms of Cells.—Cells arise by Self-origination and Reproduction.—Reproduction by Subdivision, Budding, and Endogenously.

The Animal Cell.—Forms of Cellular Tissue.—Forms of Vascular Tissue.

THE organic cell, the starting-point of every organism, vegetable or animal, consists of a vesicle or shell, with included contents. If the vesicle be of uniform thickness all over, the cell is a simple one; but if there be upon some portion of it a thickened granular spot, the cell is said to be nucleated.

The vesicle of the SIMPLE VEGETABLE CELL, more closely examined, is found to be composed of different laminæ or strata. The innermost, designated the primordial utricle, consists of an azotized substance, a member of the protein group. On the exterior of this pellicle, and, as it were, arising from its surface, lies the cell wall, serving to give protection to the parts within.

Within the primordial utricle, the cell contents present themselves of a different nature and different form, according as the species of the cell may be. In different cases they are colored of various tints, and are of various consistency, more solid or more liquid. To the cell-contents the convenient designation of endochrome is given. This interior content is not to be understood as having a homogeneous constitution, since sometimes even its colored portions are separated out and arranged in dots or spiral lines, very distinct from the remaining uncolored material.

What is the difference between a simple and a nucleated cell? Of what parts is the simple vegetable cell composed? What is the endochrome?

The active portion of such a cell consists of the utricle and endochrome conjointly, the cell wall only discharging a mechanical office. In the simple cell, all parts of the utricle appear to be endowed with equal power for carrying on the functions of the organism.

But in those cells possessing a nucleus, the energy is no longer diffused with uniformity, the nucleus concentrating much of the power in itself, and serving as a centre of activity.

There are subordinate species of cells, as the spiral and the dotted. These exhibit points of re-enforcement or thickening, such as the appearance of a thread wound spirally, or in dots here and there on the interior of the wall. There would seem to be a tendency during the development of a cell for these parts to assume a spiral arrangement.

Thus constituted, each cell runs through a definite cycle or career, having its moment of birth, its period of maturity, its time of death. During its mature life it discharges with activity the special function to which it is devoted, but in so doing becomes eventually worn out and old. The period of activity of cells of different species is very different, some passing away quickly, and others having a longer duration.

The commencement of cells is either, 1st, by self-origination, or, 2d, by reproduction. 1st. Cells arise in an obscure manner from homogeneous particles floating in a protoplasma, which, taking on development, have a vesicle thrown over them, and, being of a spherical shape, present the aspect of a cell wall and cavity. The granular content by degrees increases as the young cell grows in all its dimensions. From that granular content new cells may arise.

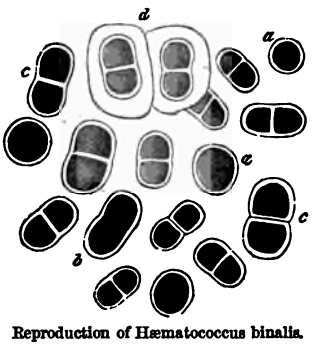
2d. Cells are reproduced from antecedent ones of the same kind by subdivision, by budding, by endogenous generation.

The reproduction of cells by subdivision is strikingly illustrated by the Hæmatococcus binalis. The manner of the process seems to be as follows. The endochrome of the original spherical cell, *a*, *Fig.* 118, begins to un-

Of what does the active portion of the vegetable cell consist? What other subordinate forms of cells are there? In what modes do cells originate? What is meant by self-origination? What by subdivision?

dergo bi-partition as at *b*, and as the dividing portions recede from one another the primordial utricle bends round them. Next a layer of permanent cell wall, of a mucous character on its exterior, is produced, which accompanies the inflection of the primordial utricle as at *c*, and, after a while, the bi-partition is complete, and the separated portions constitute distinct individual cells. The subdivision may be repeated as at *d*.

Fig. 118.



Reproduction of Hæmatococcus binalis.

The cells that have thus arisen by subdivision soon grow to the size of the one from which they were derived, and are ready for subdivision in their turn. Indeed, it often happens that traces of incipient subdivision may be detected long before the cell has reached its mature dimensions.

The reproduction of cells by budding may be illustrated by the vesicles of the yeast-plant; and though, in those cases in which the budding cell possesses a nucleus, the nucleus is not necessarily involved.

Cells are said to arise from *endogenous generation* when they make their first appearance in the cavity of a former cell, of which the endochrome exhibits a disposition to divide into many small portions, at first doubtfully, then more distinctly, and each one of these portions obtaining a covering investiture or primordial utricle for itself. The process continues until the young brood of cells has reached a certain degree of perfection, when they escape from their confinement, either by the fissuring or deliquescence of the old cell wall.

The ANIMAL CELL presents a structural arrangement differing from the vegetable in this, that it does not possess a proper cell wall, but consists of a primordial utricle and interior content alone. Its manner of reproduc-

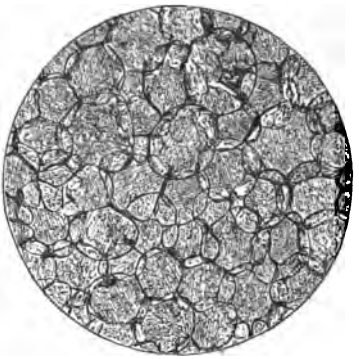
What illustration is there of cell-reproduction by budding? What is meant by endogenous generation? In what respect does the animal cell differ from the vegetable?

tion is of three kinds: 1st. From germs; 2d. By fissure; 3d. Endogenously. Where animal cells originate from germs, these seem to be granules of a substance analogous to fibrin, floating in the formative liquid. In duplication by subdivision, the import of the nucleus is shown by the fact that the action begins at it. It may be said of animal cells that the nucleus maintains a more conspicuous relation than it does in the case of vegetable ones. Reproduction in the endogenous manner is carried forward in the case of these cells in the manner described in a preceding paragraph.

OF THE CONSTRUCTION OF CELLULAR AND VASCULAR TISSUES.

By their development and juxtaposition with one another, cells give rise to continuous fabrics of various kinds, or cellular tissue. If the development of new cells occurs in a space where there is freedom from pressure, the cells maintain their original spherical form, as seen in the photograph, *Fig.* 119. But should the development occur in a confined space, or under circumstances of pressure, the intercellular spaces necessarily existing in the former case by reason of the spherical shape, are now encroached upon, and the cells assume various angular forms, such as parallelopipedons, rhombic dodecahedrons, etc. Of the former we have an example in the photograph, *Fig.* 120, representing a section of muriform cellular tissue. In other cases, with a view of giving resistance to pressure, the interior of each of the cells is fortified by a fibre, and thus arises

Fig. 119.

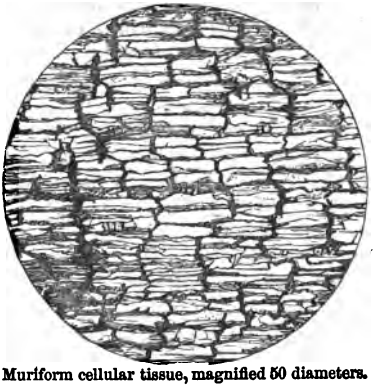


Simple cellular tissue, magnified 50 diameters.

In what three ways may it be reproduced? How does cellular tissue arise? Under what circumstances do developing cells change their form?

the tissue of which we have an example in the photograph, *Fig.* 121. Two or more fibres may in this manner be employed, and when such is the case, it is observed that they do not cross one another, the one winding from right to left, the other from left to right, but they are laid parallel to each other, and form a compound strand. In other cases the constituent cells of the tissue assume much more complicated forms, as, for instance, in the stellate variety. These more complicated forms prove that it is not altogether through the influence of a force of compression that cells assume modified shapes, but that on many occasions the disposition of their primordial utricle to branch in various directions is the true cause of the variations.

Fig. 120.



Muriform cellular tissue, magnified 50 diameters.

Fig. 121.



Fibro-cellular tissue, magnified 50 diameters.

What is fibro-cellular tissue?

This disposition to grow spontaneously in one direction rather than in another is the cause of the production of the different kinds of vascular tissue. A cell undergoing extreme elongation in one direction, either by reason of this quality of its primordial utricle, or through unequal nutrition, or other cause, gives origin to a tube. And if, of several cells thus elongated, and placed end to end on each other, the terminal portions should be obliterated either by rupture or absorption, a vessel permeable throughout is the result. In this manner vascular tissue arises. These vessels still exhibit the structural peculiarity of the cells from which they have originated in this, that they may be fortified in their interior with fibres wound in a spiral, and so constituting a spiral vessel; or wound in rings, and forming annular ducts.

Fig. 122.



Spiral vessels of cactus, magnified 50 diameters.

In like manner, through similar modifications, the varieties known as reticulated and dotted ducts arise. In these fibro-vascular tissues it frequently happens that the fortifying thread is double or even quadruple. Of spiral vessels derived from a cactus we have an example in the photograph, *Fig.* 122, and in those from the banana in that of *Fig.* 123.

The spiral vessels of plants contain air. Other tubes are for the conveyance of liquid; the laticiferous vessels, for example, which are branching tubes for transmitting the latex of plants. Again, in other cases, the interior of the vessel is more or less completely filled up by a gradual deposit of solid material, it being in this manner that proper woody fibre is formed from long, spindle-shaped cells. Vascular tissue in coniferous plants presents a peculiar dotted aspect from disc-like forms, exhibiting a pair of concentric circles, which are set at

How does vascular tissue arise? What are spiral vessels? What are reticulated and dotted ducts? What is represented in *Fig.* 124?

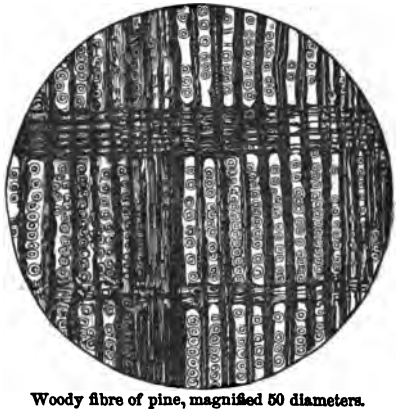
Fig. 123.



Spiral vessels of banana, magnified 50 diameters.

regular intervals upon it, as shown in the photograph, *Fig.* 124, which is dotted woody fibre from pine. The

Fig. 124.



Woody fibre of pine, magnified 50 diameters.

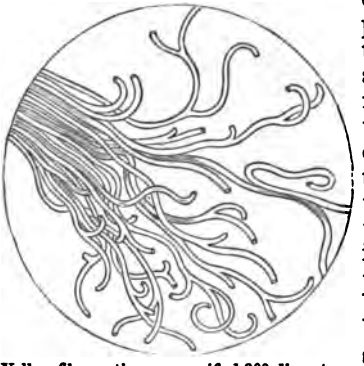
circular discs or glands run in single rows except in one place, where a double row is seen. Among true living pines more than two rows are not met with.

Animal vascular tissue arises in the same manner as vegetable, by the conjunction of elongated cells and the

How does animal vascular tissue arise?

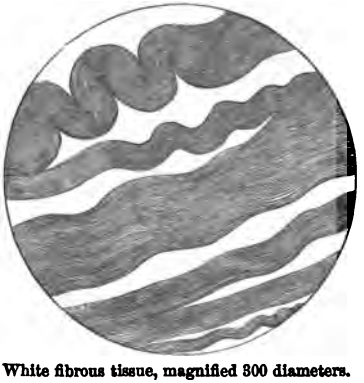
obliteration of their terminations. The physiological purposes these vessels subserve are, as in the other instance, the conveyance of gases or liquids. But fibres may form in animal fabrics without the previous intermedium of cells, either directly from fibrin, the parts of which possess the quality of agglutinating into threads, or from the coalescence under like circumstances of substances allied to gelatin, which yield the varieties of fibrous tissue known respectively as the yellow and the white, the former being composed of branching filaments, as seen in *Fig.* 125. It is unacted upon by warm acetic acid, and, from its extraordinary elasticity, is used wherever that quality is required. The latter, represented in *Fig.* 126, shows strands of a wavy appearance: it is inelastic, softens under the action of acetic acid, being thereby distinguished from the preceding, and is employed on account of its tenacity wherever resistance to extension is required, as, for example, in the ligaments of the joints. The solid animal fibres are therefore employed where physical qualities are necessary, the hollow tubes for organic processes. By some

Fig. 125.



Yellow fibrous tissue, magnified 300 diameters.

Fig. 126.



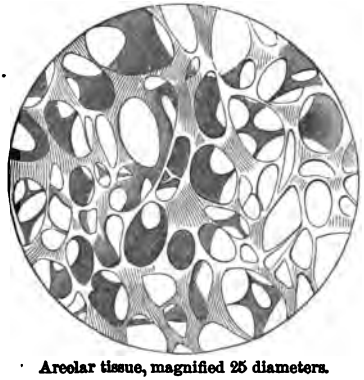
White fibrous tissue, magnified 300 diameters.

What is the difference between yellow and white fibrous tissue?

physiologists it is believed that both yellow and white fibrous tissue arise from cells.

Areolar or connective tissue, *Fig.* 127, is composed of the two preceding elements, the yellow and white fibrous, interwoven with each other so as to constitute a porous structure, with a multitude of intercommunicating spaces. It is to be understood that these interstices are wholly distinct from cells; hence the inapplicability of the term cellular, sometimes employed for this tissue. Areolar tissue is employed for uniting the various animal parts. Its interspaces are filled with a fluid, which, when in excess, is spoken of as dropsical effusion. Air, artificially or accidentally introduced at any point into it, may pass to every part, as is illustrated in cases of emphysema. The specimen from which the figure is taken was in this manner inflated.

Fig. 127.



Areolar tissue, magnified 25 diameters.

What is areolar tissue? In what respect does it differ from cellular tissue?

CHAPTER XXIII.

OF REPRODUCTION AND DEVELOPMENT.

REPRODUCTION: *Conjugation.—The Sperm-cell: its Production.—Spermatozoa.—The Germ-cell: its Production.*
Ovum in the Ovary.—Its Structure.—Corpus Luteum.
Ovum in the Oviduct.—Mulberry Mass.—Germinal Membrane.—The Chorion.
Ovum in the Uterus.—Membrana Decidua.—Placenta.
—DEVELOPMENT *of the Embryo.—Law of Von Bär.*
—Types of Nutrition.—Of Conception.—Of Gestation.—Of Parturition.—Influence of both Parents.

IN reproduction of the higher type two cells are necessary. These, differing in construction and also in function, are designated the sperm-cell and germ-cell respectively.

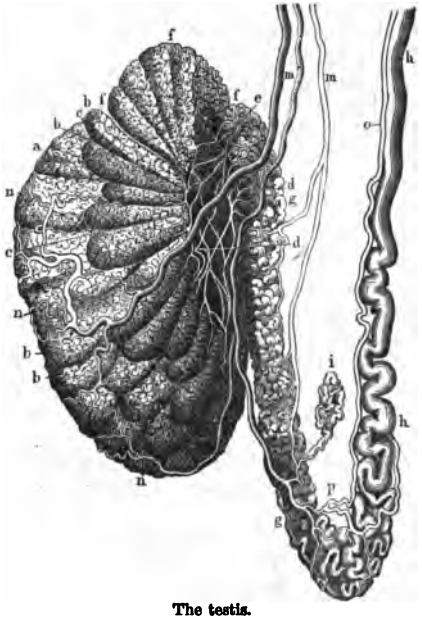
1*st. Of the Sperm-cell.*—The testes are the organs in which the sperm-cells arise in man. They are of an ovoid form; each is covered with a white envelope, the tunica albuginea. A serous membrane, folded as a shut sac, overlies this tunic. From the inner surface a number of delicate projections arise, dividing the organ into several compartments. In these compartments are lodged lobules arising from the tubuli seminiferi and their supplying blood-vessels. There are about 450 lobules in each testis; their shape is conical, the diameter of the tubes of which they are composed about the $\frac{1}{200}$ of an inch. The total length of this tubular structure is about three quarters of a mile. Before the tubuli of each lobule reach the rete testis, they cease to be convoluted, and bundles of them, uniting into larger vessels, are designated tubuli recti. In the rete testis there are from half a dozen to a dozen of these tubes, variously anastomosing with one another and dividing. They

What cells are necessary in the higher development? By what organs are the sperm-cells formed? Describe the parts of the testis. What is the length of its tubular structure?

empty into the vasa efferentia, which, from being straight, become convoluted, a series of cones arising, together forming the globus major of the epididymis. This is a convoluted canal of about twenty feet in length; descending, it receives beyond its globus minor the vasculum aberrans. It then empties into the vas deferens.

Fig. 128, human testis: *a*, testis; *b*, lobes; *c*, tubuli recti; *d*, rete vasculosum; *e*, vasa efferentia; *f*, coni vasculosi; *g*, epididymis; *h*, vas deferens; *i*, vas aberrans; *m*, branches of the spermatica interna of the testis and

Fig. 128.



The testis.

epididymis; *n*, ramification on the testis; *o*, arteria deferentialis; *p*, anastomosis with a branch of the spermatic.

The secretion of the testis must be taken for examination from the vas deferens or epididymis, before it has been mixed with the fluid of the prostate and Cowper's

Describe *Fig.* 128.

glands, or with mucus. It may be mingled with a little albumen or serum for the purpose of dilution, and, when examined with a power of 500 diameters, exhibits multitudes of moving bodies. These are the seminal animalcules, or spermatozoa.

The spermatozoa are found in the spermatic fluid of all animals after puberty, their form being different in different species. Generally they may be described as consisting of a little oval-shaped head, from which a delicate filament or tail projects.

The motion of the spermatozoa is accomplished by means of their filament. It takes place in different ways, sometimes the filament vibrating like a whip, sometimes rotating like a screw, and sometimes a spinning round, as it were, upon a pivot, occurs, the filament having been coiled like a watch-spring. The rate of motion seems under the microscope to be rapid; it is, however, estimated at an inch in thirteen minutes. In man, their entire length may be estimated at about the $\frac{1}{500}$ of an inch, the length of the head being about the $\frac{1}{2000}$, and its breadth the $\frac{1}{10000}$. They continue to exhibit motion in birds for fifteen or twenty minutes after death; in cold-blooded animals even after days.

In man, the production of spermatozoa commences between the fourteenth and sixteenth year, the time of puberty, and continues until the sixty-fifth or seventieth, or even much longer. This period of commencement is marked by a great change in the physical and moral constitution.

2*d. Of the Germ-cell.*—In mammals the female reproductive apparatus consists essentially of the ovaries, oviduct, and uterus.

The ovaries are two ovoid bodies situated on either side of the uterus. They consist of a stroma in which vesicles are imbedded: these vesicles give origin to the ova. In the manner to be presently described, the ova, being received at the fimbriated extremities of the Fallopian tubes, those tubes being therefore appropriately

What are the spermatozoa? What is the mode and rapidity of their motions? What is their size? How long may they continue their motions? At what time do they first appear? What are the essential parts of the mammal reproductive apparatus? What are the ovaries?

termed oviducts, are carried into the cavity of the uterus.

At the time of puberty in the human female, which occurs between the 14th and 16th year, a physical and moral change takes place, answering to that already alluded to as occurring in the male. From this period a sanguinolent discharge makes its appearance monthly: it is the catamenia. The interval from time to time is commonly estimated at four weeks; it varies, however, with individuals, and it is said also with climates, the discharge occurring in the hotter more frequently, and in greater quantity. It is essentially blood, deprived of its quality of coagulating by intermixture with acid mucus of the vagina. So long as these periods continue, the individual possesses the reproductive power, the first appearance of the catamenia indicating the capacity for conception, and the disappearance, at about the 45th year, its end. During gestation the catamenia are suspended, and, indeed, it is this event which is usually taken as the indication that conception has occurred.

I. *Ovum in the Ovary.*

The ovary is the organism in which the ova are prepared, these bodies arising in the following way:

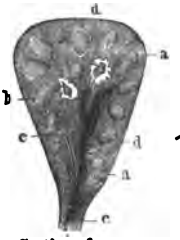
In the stroma of the ovary there occur at a time ten, twenty, or many more cells. They have received the designation of Graafian vesicles or ovisacs. They originate in the interior of the ovary, and, as they become perfected, pass to its surface, presenting themselves thereupon as prominences covered over exteriorly with peritoneum. Each of these vesicles has a membranous envelope connecting it with the substance of the ovary exteriorly, and covered interiorly with a layer of nucleated cells, designated membrana granulosa. It is filled with a fluid in which multitudes of granules float, and in its centre is the ovule. This, as it becomes mature, is pushed up toward the surface of the ovisac by an accumulation of liquid in the lower part thereof, and is so brought into close relation with the membrana granulosa at the place where it is upon the surface of the ovary. At this point there collects on the ovum a zone of

. What is the catamenial discharge? How long does it continue? What does it indicate? Describe the production of ova.

granules, to which the designation of discus proligerus is given.

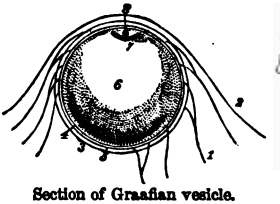
Fig. 129, transverse section through the ovary: *a*, Graafian follicle of inferior, and, *b*, of superior surface; *c*, peritoneal lamella of ligamentum latum, continued upon the ovary, and coalescing with, *d*, the tunica albuginea: in the interior two corpora albicantia (old corpora lutea) are visible; *e*, stroma of the ovary.

Fig. 129.



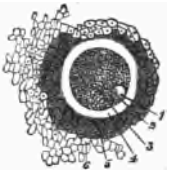
Section of ovary.

Fig. 130.



Section of Graafian vesicle.

Fig. 131.



Ovum.

Fig. 130, section of the Graafian vesicle: 1, stroma of ovary, with blood-vessels; 2, peritoneum; 3 and 5, layers of the external coat of the Graafian vesicle; 4, membrana granulosa; 6, fluid of the vesicle; 7, granular zone, or discus proligerus; 8, the ovum.

Fig. 131, ovum: 1, germinal spot; 2, germinal vesicle; 3 yolk; 4, zona pellucida; 5, discus proligerus; 6, adherent granules or cells.

The diameter of the human ovum varies from the $\frac{1}{120}$ to the $\frac{1}{240}$ of an inch. It consists of an exterior transparent membrane, the $\frac{1}{2500}$ of an inch in thickness, which, when compressed for the purpose of examination, appears like a diaphanous circle, and hence called zona pellucida. Within this zone, and inclosed by it, is the yolk, a granular material suspended in or intermingled with fluid, the granules being of different sizes; those near the pellucid zone are the largest. For the most part, the yolk consists of albumen and oil globules. Its condition, as regards liquidity, varies in different animals; in some it is almost a soft solid, so that, when water percolates through the zona pellucida, it isolates

Describe *Figs.* 129, 130, 131. What is the size of the human ovum? Of what parts is it composed? What is the zona pellucida?

the yolk by surrounding it on all sides, and parting it off from the zone. Within the substance of the yolk is a distinct cell, the germinal vesicle, which gradually makes its way from the interior to the place of peritoneal contact. As it advances to perfection, it consists of a delicate spherical membrane containing a liquid, in which granules are suspended. Upon that portion of it nearest to the place of peritoneal contact is its nucleus, the germinal spot, about the $\frac{1}{3000}$ of an inch in diameter, and consisting of yellow granules.

Fig. 132, diagram of a Graafian vesicle and ovum: 1,

Fig. 132.

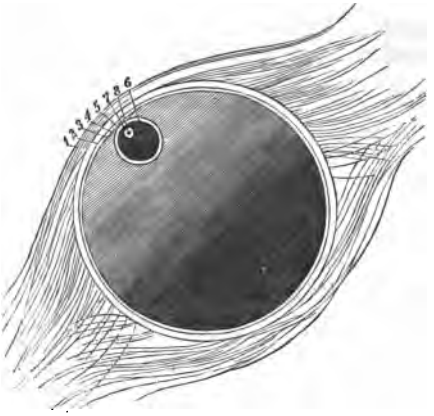


Diagram of Graafian vesicle.

stroma of ovary; 2, 3, external and internal tunics of the Graafian vesicle; 4, cavity of vesicle; 5, thick tunic of the ovum or yolk-sac; 6, the yolk; 7, the germinal vesicle; 8, the germinal spot.

The most mature ova are nearest the surface of the ovary, but are separated from its peritoneum by a thin, fibrous layer of stroma. The Graafian vesicle is, therefore, the parent of the ovum. Periodically, at the catamenia, as development is going on, the Graafian vesicle bursts, and the ovum is set free. This effect arises, in part, from the circumstance that, the space between the

Describe *Fig.* 132. How frequently do the Graafian vesicles burst and discharge ova?

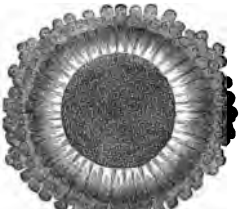
vesicle and ovum being filled with cells, those near the surface of the ovary disappear, and an albuminous liquid, accumulating below, pushes the ovum up. The ovisac, or Graafian vesicle, thus changed into a follicle, is gradually filled up, its walls wrinkling, and red-colored material, arising from the membrana granulosa, being deposited in it until it is almost filled. This deposit gradually turns yellow, and is eventually composed of cells interiorly, and fibres arising therefrom exteriorly. When the deposit is completed, a stellated cicatrix is observed in its midst. The yellow body thus arising passes under the designation of corpus luteum. If impregnation does not occur, the yellow substance forms to but a small extent, and after a time disappears. An ovum is therefore discharged at each monthly period.

II. *Fertilized Ovum in the Oviduct.*

Such being a description of the ordinary or unfertilized ovum, we have next to follow the changes ensuing if fertilization has taken place.

The spermatozoa having become enveloped in the pellucid zone or passing through it, the ovum is received by the fimbriated extremities of the Fallopian tube, along which it is carried by peristaltic contraction or ciliary motion. The first change taking place in it is the disappearance of its germinal vesicle and germinal spot. This disappearance is, however, stated by some to be preceded by a development of cells originating in the nucleus or germinal spot; nor is it the result of fertilization, since it occurs in the unimpregnated ovum. The cells of the membrana granulosa, surrounding the ovum, become first of a conical shape, but their rounded form is resumed on passing into the tube.

Fig. 133.

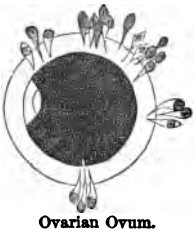


Ovarian ovum.

Fig. 133, ovarian ovum of dog, exhibiting the elongated form and stellate arrangement of the cells of the discus proligerus round the zona pellucida.

What is the corpus luteum? What is the first change taking place in the fertilized ovum? Describe *Fig.* 133.

Fig. 134.

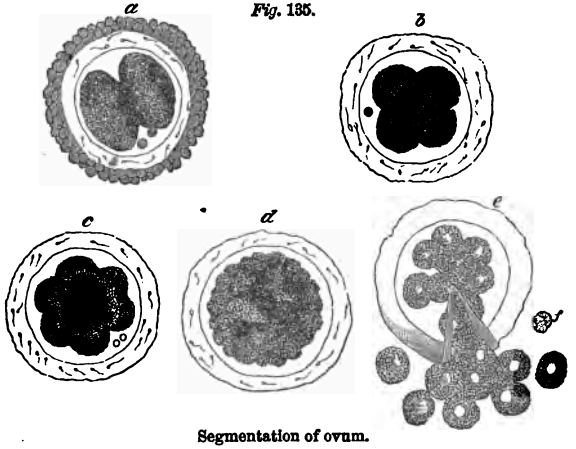


Ovarian Ovum.

Fig. 134, same ovum after the removal of most of the club-shaped cells.

The yolk is next observed to contract so as to leave a clear space between it and the zona pellucida. As the passage along the tube is taking place, the zona assumes a coating of albuminous material; this is what is called in birds the white of the egg. It eventually becomes the chorion. Meantime, after the disappearance of the germinal vesicle, a new cell, the embryo cell, arises, and this undergoes subdivision or segmentation, an effect in which the yolk itself presently becomes involved, each new or daughter embryo cell so arising assuming a part of the yolk. A constant process of bisection is thus established, the yolk dividing first into two portions, then into four, eight, sixteen, etc., each division containing a nucleated cell. At this period may be seen the spermatozoa involved in the zona pellucida, and, as the process of bisection goes on, the mass assumes a mulberry aspect, and finally becomes granular. This is, for the most part, finished by the time the ovum enters the uterus.

Fig. 135.



Segmentation of ovum.

Describe *Fig.* 134. How does the mulberry mass arise? When is the process of segmentation finished.

Fig. 135, p. 343, ova of the dog in various stages: *a*, from the oviduct, half an inch from the uterus, spermatozoids being in the pellucid zone, the yolk bisected; *b*, cells of tunica granulosa have disappeared, and the yolk is in four segments; *c*, continued advance in segmentation; *d*, the zona has become thicker, and the segmentation more complete; *e*, ovum burst by compression: some of the segments have escaped; each shows a bright spot or vesicle.

As the ovum is about to enter the uterus, each portion arising from the segmentation of the yolk has become a perfect cell. This cell formation having been accomplished at the surface of the yolk first, the cells there begin to coalesce into a membrane, with an aspect like that of hexagonal pavement epithelium, and, as the change passes toward the centre, the cells, as they form, come toward the membrane and thicken it, leaving a clear liquid within. In this manner a secondary vesicle forms within the zona pellucida: it is the blastodermic vesicle: it is the temporary stomach of the embryo. Its wall constitutes the germinal membrane, upon which the embryo arises. New cells being constantly added, the membrane increases in thickness; and here it may be remarked that, in most types, the yolk is to be considered as presenting two portions—the germ-yolk and the food-yolk; the former being immediately employed in the development of the embryo, and the latter being a stock for more advanced supply. In mammals, for whom other means of nutrition are quickly provided, the food-yolk is imperceptible, and, moreover, in them the albuminous coating of the zona pellucida is small; and in birds, the embryo of which has to be nourished independently of the parent, the quantity is necessarily large. As we have said, this albuminous covering and the zona together constitute the chorion, the exterior of which presents a rugged aspect, from the appearance of absorbing radicles, which, becoming imbedded or dove-tailed in the deciduous membrane, presently to be described, establishes the necessary connection for tuft nutrition, and thereby obtaining albumen from the parent.

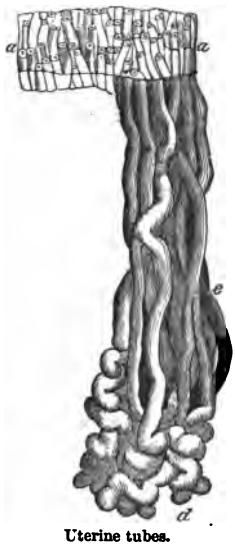
What becomes of each portion of the segmented mass? How does the blastodermic vesicle form? What is its use? What is the germinal membrane? What are the uses of the two kinds of yolk? In what manner does the chorion form?

III. *Fertilized Ovum in the Uterus.*

While the ovum is passing through the Fallopian tube or oviduct, it obtains a coating of albuminous material outside of its zona pellucida. This coating becomes the means of attachment to the uterus, and thereby of the absorption of nutriment in the following way.

The outside surface of the incipient chorion presents a layer of cells, and soon after assumes a fibrous structure. In this condition the ovum makes its appearance in the uterus, on the interior of the surface of which the mouths of a great number of follicles open. Their general appearance is illustrated by *Fig.* 136; *d*, cæcal terminations of glands; *e*, their tubes; *a*, mouths on interior of uterus. The constitutional disturbance at this time taking place, enhanced by the presence of the ovum in the organ, at once increases its vascularity; the follicles become larger, cells are abundantly developed in them, and the uterine cavity is filled with a liquid containing many nucleated cells. This plastic semi-fluid material receives the fringes of the villous coat of the chorion, now being developed; and these even find their way into the mouths of the glandular tubes; from this exudation or secretion the membrana decidua forms, though by some it is represented as being a metamorphosis of the mucous membrane itself. Meantime the ovum is coated over with a corresponding membrane, designated membrana reflexa, because it was believed to originate in the circumstance that, when the ovum reached the uterine mouth of the Fallopian tube, it there encountered the proper membrana decidua, and, not perforating it, but bearing it onward, gathered a fold, covering, or envelope.

Fig. 136.



Uterine tubes.

What does *Fig.* 136 illustrate? In what manner does the deciduous membrane form?

It is, however, now admitted that this description of the formation of the membrana reflexa is erroneous, for in reality the ovum is at no time on the outside of the mucous membrane, which is continuous from the cavity of the uterus through the Fallopian tube. The following, therefore, seems to be the more correct description. The presence of the ovum gives rise to an increased development of cells, rapidly spreading around it, and coating it all over, their points of origin being those portions of the uterine mucous membrane with which the ovum is in contact. In this way it receives its deciduous envelope, which, participating duly in its growth, is at the end of the third month in contact with the uterine decidua all over.

At the stage we are now considering, the nutrition of the embryo is conducted in a special but very temporary way. The yolk of the ovum has no stock of food to maintain the nutritive processes beyond the brief space transpiring in the passage through the Fallopian tube. The duty of nutrition is at this moment assumed by the villous coat of the chorion: this absorbs fluid exuding from the uterine decidua very much after the manner of the spongioles of a plant; but almost immediately the necessity arises of diverting more directly the albuminoid material to the quickly-growing embryo from the yolk-bag, to which it would have gone, and this new destination implies the introduction of new channels of transport, which, under the form of a vascular apparatus, are now provided.

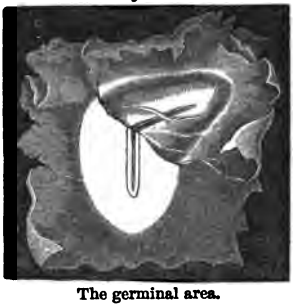
About the close of the second month, a proper vascular apparatus for the combined purposes of nutrition, secretion, and respiration makes its appearance: it is the placenta. Its origin is in the little blood-tubes forming in the tufts of the chorion, in man at one point, in ruminants simultaneously at several, and giving rise in the former case to one organ, the placenta, as has been said, in the other to many such, or, at all events, to one of a composite structure, the cotyledons. The fœtal vessels thus arising in the villi of the chorion become intermingled with vessels contemporaneously arising from the uterus; and though, in some cases, this intermingling is less complicated, so that the maternal and fœtal

What changes occur at this period in the nutritive process? In what manner does the placenta arise?

portions are separable, in man the internetting is complete, the principle being to bring the fœtal vascular tufts in such a relation with the maternal blood-sinuses, by the tufts dipping down or being enveloped therein, that the completest contact and facility of exchange, but not of intermixture, may be insured. Things are arranged in such a way that the maternal and fœtal blood do not intermingle, each being confined in vessels of its own, through the thin walls of which nutritious matter may pass and excrementitious matter repass. Every fœtal tuft has a deciduous layer upon it, and the blood brought by the curling arteries of the uterus furnishes to the fœtus its oxygen, and receives back carbonic acid, with other excrementitious matters. In this respect, respiration is carried on by the aid of a mechanism answering to the gills of fishes, the maternal arterial blood standing for the aerated water; but, besides this, the tufts have another duty to discharge—the obtaining of albuminoid material from the maternal blood. The placental mechanism is therefore much more perfect in its action than the tuft mechanism preceding it.

The germinal membrane, formed as has been described, already exhibits at one spot an opaque area of a roundish shape, consisting of cells and granules. To this the designation of germinal area is given. At this area the membrane next becomes divisible into two laminæ, and eventually throughout its whole extent, as seen in *Fig.* 137. Of these laminæ, the exterior, nearer to the zona pellucida, is the serous layer. It is the raised membrane of the figure, and in it are to be developed the nervous and muscular systems of the embryo. The interior is designated the mucous layer, and from this arise the digestive organs.

Fig. 137.

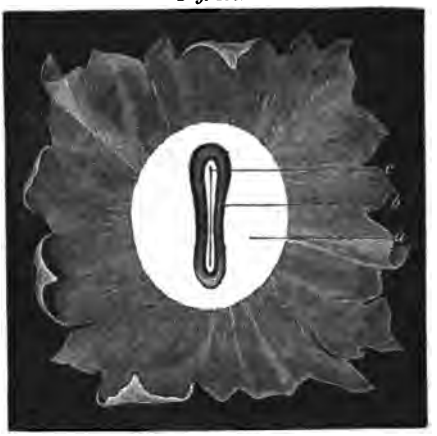


The germinal area.

What are its functions? What layers next arise in the germinal membrane? What systems arise from its serous layer? What systems from its mucous? Describe *Fig.* 137.

The germinal area by degrees loses its circular form and becomes oval, its central portions clearing off and giving rise to the area pellucida. Around this the opacity is increased, and in it blood-vessels appear; hence to this dark circle the designation of area vasculosa is applied. In the pellucid zone is next seen a delicate line, the primitive groove, *Fig.* 138: *a*, area pellucida; *b*,

Fig. 138.



The primitive groove, magnified 8 diameters.

dorsal laminæ; *c*, primitive trace. It occurs in the serous layer only, is wider at one end than at the other, the wider part being destined for the head of the embryo. On each side of the primitive groove two oval areas of cells emerge: they are the dorsal laminæ. They rise up to cover in the primitive groove, so as to convert it into a tube, with three bead-like swellings at its wider end, the elements of the prosencephalon, mesencephalon, and epencephalon, *Fig.* 139: *a*, cephalic end; *b*, chorda dorsalis; *c*, vertebra; *d*, dilatation. On the internal part of the lamina nervous matter begins to form, the rudiment of the cerebro-spinal axis. In the bottom of the groove is the trace, chorda dorsalis. The groove itself, converted into a tube, constitutes the cen-

Describe *Figs.* 138, 139. In what manner does the cerebro-spinal axis arise?

Fig. 189.



Origin of the brain upon the spinal cord, magnified 8 diameters.

tral canal of that axis, its completion into the tubular shape occurring first in the middle, and then up and down. The form of the lateral masses varies as development goes on.

A line of cells running lengthwise in the primitive groove is the origin of the chorda dorsalis, on which the rudiments of the vertebral column appear. In the amphioxus and myxenoid fishes development in this direction stops at this point, the chorda dorsalis being the permanent structure. The vertebræ now emerge under the aspect of square plates, and the dorsal laminæ, prolonging themselves outward and downward, as it were, by an offshoot, produce the ventral laminæ, which close in the abdominal walls, and so form the boundaries of the trunk. Simultaneously a new layer of cells arises between the serous and mucous layer of the germinal membrane, at the area vasculosa, and in this intercalated lamina the vascular system forms and blood corpuscles appear, capillary vessels arising from the coalescence of nucleated cells, the touching ends of which become pervious. As the process goes forward, a network of such vessels is constructed, and it is to be particularly re-

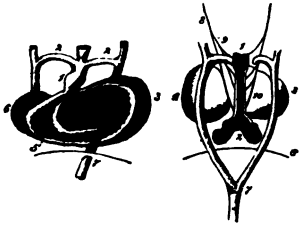
How are the vertebræ produced? In what manner are the blood-vessels developed?

marked that this takes place and that the blood is in circulation prior to the existence of the heart. Around the extending blood-vessels or vascular area runs a circular capillary called the terminal sinus in the first stage of the process, but this disappears as the vessels extend all over the germinal membrane. The extension of these vessels is in part accomplished by the cells from which they have arisen elongating themselves into processes.

The heart appears first as a canal or tube, arising in the vascular layer from a columnar mass of cells, of which the inner ones have deliquesced to form a tube. This then becomes tri-chambered, containing an auricle, a ventricle, and the bulbus arteriosus. Subsequently the auricle and ventricle are each divided by septa, that in the ventricle being commenced about the fourth, and finished about the eighth week. The auricular septum is not completed until after birth.

Fig. 140 shows the human heart at about the fifth week: A, the heart opened on the abdominal aspect; 1, the bulbus arteriosus; 2, 2, two aortic arches, uniting posteriorly to form the aorta; 3, the auricle; 4, the opening from the auricle into the ventricle, 6, which is laid open; 5, the septum rising from the lowest part of the cavity of the ventricle; 7, the vena cava inferior: B, view from behind; 1, the trachea; 2, the lungs; 3, the ventricle; 4, 5, the large atrium cordis, or auricle; 6, the diaphragm; 7, the aorta descendens; 8, the pneumogastric; 9, its branches; 10, its continuation.

Fig 140.



Fœtal heart.

As soon as the capillary system is fairly established, the change in the character of the function of nutrition alluded to is accomplished, and in those animals depending for their development on a food yolk, it is eventually entirely covered with ramifications of these vessels. The blood-cells of the first order or series are evolved from the nuclei of the cells which coalesced for the formation of blood-vessels.

Describe *Fig.* 140.

The development of the embryo still continuing, it assumes a form aptly described as resembling that of a boat placed upside down, the bottom of the boat rising higher and higher above the surface of the germinal membrane, and lifting with it that portion of the membrane to which it is attached. The two ends of the boat-shaped body bend under toward one another; the larger of the two is destined to become the head of the embryo. As this elevation takes place, the embryo becomes separated by a constricted space from the surrounding germinal membrane, its abdominal parietes being still open and in contact with the yolk. From the layer thus lining the interior of the cavity of the embryo, the intestinal canal arises as a tube from the coalescence of a pair of lateral ridges, and the surrounding and exterior portions of the germinal membrane, elevating themselves above the constricted space, coalesce over the back of the embryo, and thus inclose it in a sac. This sac constitutes the amnion, and in this manner, by folding, the interior of the germinal membrane is used as a digestive surface, the outer as one for secretion. The umbilical cord obtains a sheath from the amnion, which at one end is continuous with the skin of the fœtus, and the other is reflected over the surface of the placenta. The amnion therefore constitutes a closed sac, containing a fluid, the liquor amnii.

The place at which the germinal membrane is constricted, so as to be able to act as a digestive surface to the embryo, though linear at first, is gradually narrowed down, and constitutes the umbilicus. This constricted part is now the omphalo-mesenteric duct. It communicates with the cavity of the yolk-sac, which, at this stage of development in mammalia, is the umbilical vesicle. In birds, the yolk-sac is carried completely into the abdomen through the umbilical opening; in mammals it remains exterior. It does not appear that the contents of the yolk are directly absorbed from the cavity of the sac, but they are carried by the ramifying vessels to the liver. These vessels are therefore counterparts of the mesenteric. Eventually folds arise on the lining mem-

In what manner is the embryo developed as a boat-shaped body? How does the amnion form? How does the intestinal canal arise? What becomes of the yolk-sac in birds and mammals respectively?

brane of the yolk-sac over which these vessels pass, and facilitate absorption. In fish, at this stage, the yolk-bag hangs down, and respiration takes place upon its surface.

From the caudal extremity of the embryo the allantois emerges as a mass of cells, the interior liquefy, and the exterior then constitute a sac. In birds and in reptiles it reaches considerable development; in the former extending entirely over the yolk-sac, but in mammals it is soon replaced and shrivels up. It discharges the function of a urinary bladder, and, indeed, a portion of it continues to do so in man. Its disappearance is the signal that the embryo is now depending on the placenta.

To return now to the development of the circulatory system. At about the end of the eighth week, as we have seen, the ventricle is divided by a septum, the division of the auricle not occurring till a little after, and even then not being perfect, an aperture, the foramen ovale, existing. This is the state of things at about the twelfth week: of the five branchial arches two disappear, the aortic bulb then divides into two tubes, which are to be the aorta and pulmonary artery respectively. Next, one of the branchial arches forms the subclavian and carotid arteries. Of the middle pair, the right is obliterated, but the left remains to constitute the arch of the aorta. Of the lowest pair, the right forms the right and left pulmonary arteries, and the left constitutes the ductus arteriosus.

The blood-system having reached its full development, the fœtal circulation may be described as follows: From the placenta oxidized blood is brought through the umbilical vein, a part passing into the ascending cava through the ductus venosus, and the rest into the liver through the vena portæ, from which, by the hepatic vein, it also reaches the ascending cava. In its passage to the heart it becomes adulterated with blood derived from the trunk and lower extremities. It next goes into the right auricle, and, to some extent, is kept from contamination with the venous blood coming through the descending cava by means of the Eustachian valve, which directs the arterialized blood through the foramen ovale

What is the first appearance of the allantois? Describe the order of development of the circulatory system. Describe the fœtal circulation.

into the left auricle, from which it gains the left ventricle, and also directs the venous blood of the descending cava into the right ventricle. The blood in the left ventricle is driven therefrom into the ascending aorta, and supplies the head; but the venous blood in the right ventricle is driven therefrom through the pulmonary artery and ductus arteriosus into the descending aorta, and, mingling with the arterial blood therein, passes to the trunk and legs. Of this blood a portion is then carried to the placenta to be arterialized.

From the description thus given, it may be gathered that, up to the period of birth, three distinct types of nutrition have been followed. They may, with sufficient accuracy, be designated, 1st. Yolk nutrition; 2d. Tuft nutrition; 3d. Placental nutrition. To these may be added the two followed at a later period; 4th. Lactation, and, after the dental mechanism is supplied, 5th. The diet of mature life.

During the development of any new organism, the new parts uniformly arise from the old ones; they are not built from foreign materials depositing themselves upon new centres, but are educed by the unfolding, enlarging, and modeling of parts already existing. An organism is not developed as we enlarge a house, by building part to part, but it all expands from one common or single centre. As the sphere of its expansion becomes greater, the opportunity arises for devoting different regions to different uses, and thus offices which were confusedly intermingled become separated out, and as, in social undertakings, the division of labor gives greater perfection to the work, so in this, functions which, because they were blended, were imperfectly discharged, now assume precision and power, because they are disentangled from what were perhaps countervailing conditions.

By these considerations, we are gradually led to the general law of development, first recognized by Von Bär, and passing under his name. This is somewhat obscurely enunciated in the following terms: "The heterogeneous arises from the homogeneous by a gradual process of change." By this it is meant that, in the process of

How many different types of nutrition are there? In what manner do new parts arise? What is the law of Von Bär?

development, the stages are not from forms that are of a degraded to those of a higher type, but that from the general the special, which was therein included, is gradually evolved.

Respecting the development of special organs, it may be remarked that of the permanent ones, the vertebral column is one of the first to appear; it shows itself under the form of isolated quadrangular elements. The gelatinous cellular structure, chorda dorsalis, acquires a sheath, which assumes a fibrous structure, and from this, in the lower vertebrates, the vertebræ are evolved. In man, the elementary quadrangular plates are considered to have an independent origin. As they increase in number and size they surround the chorda, and projections springing from their superior surface form arches to envelop the spinal cord. Each vertebra, therefore, is constructed by the union of two pieces, one on either side. These first assume the condition of cartilage, and, later, the body and arches ossify from separate points. The chorda dorsalis, which has, during this development, been gradually evolved in the bodies of the vertebræ, disappears.

The bones of the skull are metamorphosed vertebræ, of which four appear to have undergone change. To these the auditory, gustative, optic, and olfactory nerves are respectively related, in the same manner that the spinal nerves are to their vertebræ.

In the descriptions given in the preceding part of this work, incidental allusion to a sufficient extent has been made to the development of most of the apparatus of organic and also animal life. It may therefore here be briefly stated that the alimentary canal originates in the pinching off of a part of the blastodermic vesicle below the spinal column. At first it is a straight tube, communicating about its middle with that vesicle, but after a time showing its eventual division into œsophagus, stomach, large and small intestines, assuming an oblique position on the part to be occupied by the stomach, and then curving in the region of the intestine. From a part of this tube the liver emerges as a thickened deposit of

How is the vertebral column developed? From what do the bones of the skull originate? How does the alimentary canal arise? What is the origin of the liver?

cells, into which the wall of the intestine bulges so as to form a kind of sac, and from this rudiment a ramified structure arises, which at last recedes from its place of origin, and is connected with the intestine by the hepatic duct. The commencement of this structure is about the third week, but it proceeds with so much rapidity that in the third month it nearly fills the abdominal cavity. The functions of the liver at this period have already been pointed out, the meconium it secretes being modified bile. In like manner, from the digestive tract, the pancreas and salivary glands originate from masses of cells, ducts being formed by deliquescence of portions within. From the alimentary canal, also by budding and deliquescence, the lungs arise, their cavity communicating at first by several apertures with the pharynx. This occurs about the sixth week. These organs are gradually removed from the place of origin, as in the case of the liver.

The Wolffian bodies are temporary urinary organs, preceding the kidneys, and eventually disappearing. They are of an ovoid shape, and consist of a duct from which transverse canals branch forth, the duct discharging into the sinus urogenitalis. They originate about the end of the first month, and commence to degenerate in the third. In fishes they remain as the permanent urinary apparatus. The testes or ovaries arise from the inner margin of the Wolffian body, the former being guided into the scrotum by the gubernaculum. This descent commences between the fourth and fifth month, and is completed at birth or shortly after.

Among the indications that conception has occurred are usually enumerated, stoppage of the menses, the placental murmur, the development of the mammary gland, its sense of pain or tenderness, the color of the areola, the turgescence of the areola and nipple, irritability of the stomach. Quickening, as it is termed, usually occurs about the eighteenth week, and parturition in the fortieth, or at the close of 280 days. With respect to this, it is admitted that the term may be possibly prolonged, in very rare cases, by 40 days. The French laws

What substance does it at this early period secrete? How do the lungs arise? What is the function of the Wolffian bodies? What are the signs of conception?

legitimatize a child born within 300 days; and that such variations of the proper term may occur is proved by observations made upon domestic animals, in which the duration of pregnancy can be ascertained with precision. In the cow, which has the same period of gestation as the human female, the shortest period hitherto observed is 213 days, the longest 336. The shortest period at which human parturition can occur, consistent with the viability of the child, appears to be about 23 weeks.

The act of parturition in its first stage is to be referred to a contraction of the muscular fibres of the fundus and body of the uterus with a synchronous relaxation of those of the cervix. At a later period the contraction of the expiratory muscles assists. After birth is accomplished, the mouths of the uterine vessels are closed through the contraction of the organ, the lochial discharge carrying with it any disintegrated residues of the deciduous membrane, and also large quantities of fat, derived probably from the degeneration of the uterine structure itself.

That both parents are concerned in imparting characteristics to the child there can be no doubt: it is fully established where they are of different races, as white and black, or white and red; and equally in the case of animals, as in mules, produced by the mixture of different kinds. It is scarcely necessary to remark that this extends to the communication of more refined peculiarities, the resemblance of countenance, figure, gesture, and even mental qualities, family likenesses we daily observe. These impressions are of a much more profound character than might at first be supposed, as is proved by the fact that the third generation will exhibit peculiarities belonging to its progenitors, though those peculiarities have not occurred in the second.

What is the period of gestation? In what manner is the act of parturition accomplished? What does the lochial discharge remove? How is it certain that both parents impart characteristics to the child?

CHAPTER XXIV.

THE GROWTH OF MAN.

Infancy.— Weight and Size of the Infant.— Weight and Size at subsequent Periods.—Development of the Intellect.—Maturity of Man.
Mental and Physical Decline.—Mortality at different Periods of Life.— Comparative Structure, Functions, and Mortality of the two Sexes.

At birth, the human infant is the very representative of weakness and imbecility. Though, unlike many other mammals, it opens its eyes at once, it exhibits no tokens of visual perceptions; though it may be subjected to sounds or noises of various kinds, it takes no notice whatever of them. This condition of inertness is followed by a condition of confused sensation, which by degrees is succeeded by a capability of appreciating special ideas. The earliest period of conscious existence is a scene of pain, the life of the infant being divided between sleep and crying; from its slumbers it is awakened only by the pains of hunger; nor is it until after the lapse of many days, or even weeks, that the first smile is seen. It is too feeble to turn from side to side, but remains in the position in which it was placed. Its skin at birth covered over with a whitish incrustation, the vernix caseosa, becomes reddish; the depth of this tint, however, shortly passes away. At this period, moreover, life is purely vegetative, the infant feeding and sleeping. The biliary matter, meconium, which had accumulated in its intestine during fœtal life, is discharged in the course of a day or so after birth, and the digestive apparatus enters on its functions with activity.

It is said that the infant smiles soon after it is forty days old; though it can cry it can not shed tears. Before long it gives indications of its satisfactions and dislikes. The power of moving in an erect posture is gain-

Has the human infant visual perceptions at birth? What is the vernix caseosa? What is meconium?

ed by it in the course of a year, and by the close of that time it can masticate. Of its teeth, the central incisors appear about the seventh month, those of the lower jaw first; the lateral incisors about the eighth or tenth, the anterior molars about the twelfth, and the canines about the eighteenth, the posterior molars being cut between that time and three years. The average date of the appearance of the permanent teeth is, the front molars about the seventh year; middle incisors, eighth; lateral incisors, ninth; anterior bicuspids, tenth; second bicuspids, eleventh; canines, twelfth to thirteenth; second molars, twelfth to fourteenth; and the last molars from the seventeenth to the twenty-first year.

The power of articulate speech is displayed within twelve or fifteen months, some letters being more easily gained than others; among them are A, B, P, M.

Throughout infancy and childhood, the features, and even the gestures, indicate the profound constitutional changes going on. The countenance, instead of expressing pleasure or pain in the aggregate by smiling or crying, as was the case at first, gains the faculty of representing every grade of feeling. Long before maturity is reached we read without difficulty the thoughts passing in the mind from the movements of the lip or the eye, and the painter can express every shade of feeling, and every emotion, by the mere configuration of the outward form.

The monthly growth of the fœtus for six months before birth is about two inches. At birth, the mean length of boys is 18½ inches, and of girls 18⅛ inches, the former being therefore a little the longer.

At sixteen or seventeen years the growth of girls is relatively as much advanced as that of youths of eighteen or nineteen. For the most part, the inhabitants of towns are taller than those of the country. The full height is not reached, in some instances, until twenty-five years; in very warm and very cold climates it is more quickly attained. The recumbent position is regarded as being favorable to growth, and, influenced by

How long is it before the teeth are cut? What is the order of their appearance? What letters are first articulated? What is the mean length at birth? What is the growth of boys and girls relatively to each other? When is the full height reached?

his own weight, an individual is shorter in the evening than when he first rises from bed in the morning.

With regard to the rate of growth, it is most rapid immediately after birth, and continually diminishes until about five years, the epoch of maximum of probable life. It then remains equable to about sixteen years, the annual growth being 2½ inches. After puberty it declines, being, from sixteen to seventeen years, 1½ inches, and during the next two 1 inch only. The annual increment relatively to the height then attained continually diminishes from birth. The fœtus grows as much in length in a month as the child from 6 to 16 years does in a year. The limits of growth of the two sexes are unequal, because women are smaller than men, terminate their growth sooner, and annually grow less. Individuals in affluent circumstances may often surpass the standard height, but misery and fatigue are liable to produce the opposite effect. Longevity is generally less for persons of great height.

As to the maximum and minimum of height, it may be remarked that Frederick the Great had a Swedish body-guard whose height was eight feet three inches; and, on the other hand, Birch states that there was an individual, 37 years old, whose height was sixteen inches. In view of these and other such facts, Quetelet fixes on 8 feet 3 inches as the maximum, and 1 foot 5 inches as the minimum of height; he gives as the mean 5 feet 4 inches. Half the men of France, at the age of conscription, are between 5 feet 2 inches and 5 feet 6 inches, but the wars incident on the great Revolution made a permanent impression on the French in this respect by lowering the standard through the consumption of the taller men. M. Quetelet moreover remarks, that in ten millions of men there is but one more than 6 feet 8 inches, and one less than 4 feet. There is reason, however, to believe that this statement will not hold good of America.

As regards weight, new-born boys are heavier than girls. An average taken from 20,000 gives 6¼ lbs. as the weight at birth; the maxima and minima have been 10½ lbs. and 2¼ lbs. For about a week after birth the weight diminishes, owing to the effect of aerial respira-

What are the maxima and minima of height? What is the mean weight?

tion. The difference in weight between the two sexes gradually diminishes until about the twelfth year, when an equality is reached. The maximum weight is attained about 40, and as 60 is approached a diminution is perceived, which reaches 12 lbs. at about 80 years, the stature likewise correspondingly diminishing by about $2\frac{3}{4}$ inches; the female reaches her maximum weight somewhat later, at about 50 years. The extreme limits of weight in men are 108 lbs. and 216 lbs.; in women, $87\frac{1}{2}$ lbs. and $206\frac{1}{2}$ lbs. The mean weight at nineteen is nearly that of old age in both sexes. At full development the male and female weigh almost exactly 20 times as much as at birth. In the first year the infant of both sexes triples its weight. It requires six years more to double that, and thirteen to quadruple it. Immediately after puberty both sexes have half their ultimate weight. Between the ages of 25 and 40 the mean weight of the male is $136\frac{1}{2}$ lbs., and of the female $120\frac{3}{4}$ lbs.

Arrived at maturity, the system of man commences to decline, the epochs of the maximum of physical and mental strength not, however, coinciding; that for the former occurring at about the 25th year, but that for the latter not until between the 45th and 50th year. At this period, when the powers of imagination and reason have reached their highest degree, the liability to mental alienation and insanity is also at its maximum. Somewhat later, the physical system plainly betrays that it is pursuing its downward course, retracing the steps through which it passed forward to development. Soon there is an evident decrease of weight, the nutritive operations being no longer able to repair the waste of the body. There is also a diminution of the height. This corporeal decay is the signal for a depression of the mental powers, the first which begins to yield being probably that of concentrating or abstracting the thought. As years pass on, external impressions exert a diminished influence, and he who at an earlier period reached the meaning of things, as it were, almost by intuition, now casts his eyes over page after page with-

At what period is the maximum weight attained? What are the limits of weight in men and in women? When is the maximum of physical and of mental strength attained? What is the order of their decline?

out an idea being communicated to his mind. The old man querulously complains that he reads his book, but does not understand what it means. With this failure of perception the powers of memory decline, recent events fading away first, but those of early life being recollected longest.

The mortality of towns is greater than that of the country. As we advance from the midst of the temperate region toward the equator or toward the poles, it also increases: thus, in the northern portions of Europe, the annual mortality is as 1 to 41; that of Central Europe, 1 to $40\frac{8}{10}$; that of Southern Europe, 1 to $33\frac{7}{10}$. Considered as respects different periods of life, the rate of mortality varies very much. Of both sexes, 22 per cent. die before they are one year old, and 37 per cent. before they are five years old. Male infants are, however, more liable to die immediately after birth than female, but at the close of about two years their mortality is the same. Nine twentieths of the whole number born die before they are fifteen years of age, that is, before they have become useful to the community.

The mortality among girls increases between 14 and 18, and among men between 21 and 26. In France and Belgium, from 26 to 30 is the epoch of marriage, and at this period the mortality is the same in both sexes. It then increases for the women during the years of child-bearing, and afterward again becomes equal for both. At 25 years half the births are dead. The mean life may be estimated at 33 years. The maximum expectancy of life is at 5 years, at which age the risk of mortality is suddenly reduced, and becomes small till puberty, when, especially among girls, it becomes great. From 60 to 65 the chances of life are again at a minimum.

To the foregoing statements, in which contrasts have been drawn between the male and female, the following may be added: Not only is there a difference in the entire stature, but the different portions of the body have not the same relative size. The capacity of the skull in the female is less; the body is longer; the lower ex-

What is the mortality at different periods of life? What is the relative mortality of the two sexes? What is the difference in structure of the male and female?

tremities shorter; the pelvis of greater size, especially in its transverse diameter; the heads of the thigh bones, therefore, farther apart, and the bones themselves including a larger angle than in the case of the male; the chest and the abdomen are respectively more convex; the transverse diameter at the shoulders smaller, and the upper extremities, like the lower, shorter; the hands and feet, fingers and toes, of less size. The surface presents a more elegantly rounded form, without angularities; the skin thinner and more translucent; the hair of the head is longer and finer, but other portions of the skin less covered with hair; the nails smaller and thinner.

The strength of the female is to that of the male as 16 to 26. Her muscles contract with less energy, and are more easily wearied. The peculiarities of the construction of the bones of her pelvis and chest respectively give rise to peculiarities in the movements of the lower and upper extremities; hence the characteristic manner of walking and movement of the arm in attempting to throw a stone. In the chapter on the voice we have already pointed out the female peculiarities in speaking and singing, and its more acute quality.

With respect to her moral and intellectual peculiarities, these are manifested from the earliest infancy in the sports and games which she instinctively follows. Coming to maturity more rapidly than the male, she abandons these, though they may still be enjoyed by boys of her own age, whom, for the course of a year or two, she regards with neglect or even disrespect, a feeling soon after to be followed by timidity. Education and the position in which she may have been placed may, to a certain extent, control or disguise her habits, but they can never wholly obliterate the striking predominance of her moral over her intellectual qualities, as compared with man. Essentially religious, her faith is applied to almost all the ordinary affairs of life, though when she finds that she has been deceived she is ever distrustful. From the earliest times it has been remarked that her revenge, more particularly when it concerns wounded pride, is implacable. Much more than the

What is their relative strength? What are their relative moral and intellectual peculiarities?

male she is delighted with the adornments of dress. Her reasoning powers are less vigorous, though her sensations are more acute, yet she bears pain with more resignation than man. Her judgment is not so evenly balanced, and is often perverted by the preponderance of her feelings.

The physiologist who is thus obliged to speak of the constitutional and mental imperfections of the female, may be permitted to turn with delight from the dry details of statistics and anatomy to the family and social relations, for it is therein that her beautiful qualities shine forth. At the close of a long life, checkered with pleasures and misfortunes, how often does the aged man with emotion confess that, though all the ephemeral acquaintances and attachments of his career have ended in disappointment and alienation, the wife of his youth is still his friend. In a world from which every thing else seems to be passing away, her affection alone is unchanged; true to him in sickness as in health, in misfortune as in prosperity, true in the hour of death.

CHAPTER XXV.

OF SLEEP AND DEATH.

Causes of the Necessity for Sleep.—Its Duration and Manner of Approach. — Manner of Awaking. — Cause of Night-sleep.—Increased Warmth required. — Connection of Sleep and Food.
Of Dreams: their Origin and Phenomena.
Of Death.— Old Age.—Internal Causes of Decline.— Death by Accident and by Old Age. — The Hippocratic Face.—Final Insensibility.

OF SLEEP.

ONE third of the life of man is spent in sleep, a condition of modified sensibility, in which the mind performs its functions in an imperfect way, and voluntary motion is nearly suspended. This state, occupying so large a portion of the short period of time allotted to us, is therefore well deserving of the consideration of the

What portion of life is spent in sleep?

physiologist, and the more so since it presents, in the various phenomena of dreams, significant illustrations of the manner of action of the nervous system.

All animals sleep. Many, perhaps most, dream. The necessity for a season of repose arises from the preponderance of the waste of the system over its repair during our waking hours. By bringing the animal functions into a condition of rest, an opportunity is afforded for renovation, and the equilibrium can be maintained.

In early infancy, when it is necessary for the nutritive operations to be carried forward with the utmost vigor, and attended with as little waste as possible, the whole time is spent in sleeping and eating. The waking period is gradually increased as the child advances, but not so as to make it continuous, for the day is broken into intervals of sleep. Even at three or four years of age we sleep more than once a day. In mature life eight hours are on an average required, but the precise time varies with different individuals, and even with the same individual in different constitutional states. The time is not, however, always a true measure of the amount of rest, for sleep varies very much in the degree of its completeness or intensity; there is a slumber so disturbed that we are unrefreshed by it, and a sleep so profound that we awake weary. Old age, as it advances, admonishes us to spare the system as much as we may, for repair is conducted with difficulty; and this period, characterized by its resemblance in so many respects to childhood, like it, is often marked by frequently-recurring and prolonged slumber. Moreover, various accidental and other circumstances are liable at all times to disturb its proper periodicity—a warm afternoon, a hearty dinner, an ill-ventilated apartment, monotonous sounds, the attention devoted to one object, bodily quiescence, ceasing to think, the use of narcotics, extreme cold, a horizontal position, etc.

Sleep is commonly preceded by a sense of drowsiness of more or less intensity, gradually followed by a loss of sensibility. Objects cease to make an impression on the eyes, the lids become heavy and close. If we are

What are the causes for the necessity of sleep? Is there any fixed period for the duration of sleep? What is the order in which the senses are affected?

not in the horizontal position, but require muscular support, as in sitting, the head droops, and the hands seek a support. Successively the senses of smelling, hearing, and touch pass away, as the sight has done; but, before this progress is completed, we start at any sound or disturbance, voluntary muscular action being instantly assumed, though in the midst of a surprise. We are nodding. If we are in the horizontal position, as in bed, the body is thrown into a form requiring the least muscular exertion — the limbs are semiflexed. As sight, smell, hearing, touch, again in succession fail, all voluntary motions cease, those now executed being of a purely automatic kind. The eyes are turned upward and inward, the iris is contracted, the heart and the lungs act more slowly but more powerfully; a gentle delirium, which exists while the centres of the special senses are coming into repose, introduces us to profound and unconscious sleep.

This condition of profound sleep, though it may be quickly, is yet gradually reached by passing through certain well-marked stages. Once gained, we sleep with heaviness in the early part of the night, and more and more lightly as morning approaches. It would, however, be erroneous to suppose that this falling into insensibility and awakening are perfectly continuous events; there are, undoubtedly, subordinate periods of more and less complete repose, but under no circumstances are we ever aware that we are asleep.

At any time of the night sleep may be abruptly broken, the mind resuming its power after passing through a momentary interval of confusion. Toward the close of the customary time, the senses resume their power in an order inverse to that in which they lost it—the touch, the hearing, the smell, the sight. For a short period after awakening, the organs seem to be in a state of unusual acuteness, more particularly that of sight—an effect arising from the obliteration of the vestiges of old impressions. From profound sleep we pass to the waking state through an intermediate condition of slumber. In the former, the movements we may execute, under the influence of external impressions, are wholly of an automatic kind, such as turning in bed in

What is the order in which the senses are restored on awakening?

various positions. The length of time spent in sleep and slumber respectively is by no means constant, many causes increasing the one at the expense of the other. On awakening, we are apt to indulge in certain muscular movements—we rub our eyes, stretch, and yawn. If we are suddenly aroused, our motions are feeble and uncertain on attempting to walk at once; but if we spontaneously awake at an unusual period, and more particularly if it be toward morning, we commonly remark a clearness of intellect or mental power. Many of our most judicious and correct conclusions occur to us under these circumstances.

Though it is said that the sleep of man lasts about eight hours, there are many variations. Authentic cases are on record in which individuals have, for a considerable time and apparently without injury, slept only for one hour, and others in which that state has been prolonged for an entire week. Man shows much greater differences than other animals; birds, for instance, sleep lightly, and cold-blooded animals generally profoundly. Since the object of sleep is to afford an opportunity for repairing the waste of the system, the length of the needful time depends on conditions that are themselves variable: the extent of the antecedent waste, and the rapidity of the repair. In winter we sleep longer and usually deeper than in summer, for the hourly waste in winter is greater. Habit, however, controls us very much.

It has been supposed by some that it is to habit that our tendency to sleep at night is to be imputed. It is, however, more properly to be attributed to the ordinary circumstances of our life—the day being spent in muscular or mental exercise, since we can then see to perform our duties, and this tax upon the system being necessarily followed by a feeling of weariness. Those animals which seek their food in the dark sleep by day. It is not, therefore, to any external physical condition that we should impute our nocturnal sleep, but to the interior condition of our system, though it is quite true that physical agents, such as cold, and others that have been mentioned, will provoke a sensation of drowsiness.

Is there any constant period for slumber and sleep respectively? What are maxima and minima durations of sleep? What is its object? What is the cause of nocturnal sleep?

In sleep we require additional warmth, and this we obtain by instinctively using more clothing for the purpose of economizing the animal heat. The amount of caloric generated in the system is diminished through the cessation of muscular exercise, and therefore reduction of decay. The same may be said, to a certain extent, of the waste of the brain through its intellectual acts, and of the nervous system generally. This diminished amount of interstitial death corresponds to a diminished respiration, the hourly amount of oxygen consumed exhibiting a decline. The negro, who is much more sensitive than the white man to this decline of temperature, instinctively envelops his head with clothing, so that the air may be warmed by its contact therewith before it enters the respiratory organs. For the same reason, he sleeps with his head toward the fire, while the white man sleeps with his away. On similar principles we may account for the control which food has over sleep, the one seeming, to a certain degree, to replace the other. The French proverb says, "He who sleeps, dines," and this is true; for during sleep the waste of the system is reduced to a minimum, and the necessity for food correspondingly diminished. The quality of the food likewise exerts an influence on the length of sleep, for that which is of a nutritious kind, and easily assimilated, can more speedily execute whatever repairs the system may demand. It is probably owing to his variable diet that, even in a state of perfect health, man is so variable a sleeper, and that animals, the nature of whose food is so constant, sleep with so much uniformity.

As the necessary repairs are accomplished, we pass through a condition of slumber, and our organs gradually awake in the manner that has been described. It is during this intermediate passage, that is, toward the morning chiefly, as the brain is resuming its functions, that dreams occur. They may, however, happen at any other period of the night, though then they are liable to present greater incongruities and more obvious violations of the proper order of events. It is quite correct

Why is increased warmth required? What differences are remarked between the sleeping of the white man and the negro? In what manner do dreams arise?

that morning dreams are more likely to be prophetic, for they are more likely to be in themselves true.

Dreams never strike us with surprise, no matter what may be the extraordinary scenery they present—no matter how great the violations of truth and reality. The dead may appear with the most astonishing clearness; their voices, perhaps long forgotten, may be heard; we may be transported to places where we have spent past years of our lives; combinations of the most grotesque and impossible kinds may be spread before us: we accept all as reality, perhaps not even suspecting that we dream. The germs from which have originated all these strange combinations are impressions stored up in the registering ganglia of the brain, more particularly in its optic thalami. These, as outward impressions have for the time ceased, are enabled to attract the attention of the mind, and emerge from their latent state. That all dreams originate in such impressions is illustrated by the history of the blind, who still dream of things that they formerly saw.

One of the most extraordinary phenomena presented in the dreaming state is the instantaneous manner in which a long series of events may be offered to the mind, the exciting cause being truly of only a momentary duration. Some sudden noise arouses us, and, in the act of waking, a long drama connected with that noise appears before us; or, in like manner, we are disturbed perhaps by a flash of lightning, and with that flash occurs a dream which seems to us to occupy a space of hours or even days, so many are the incidents with which it is filled. It has long been known that a like peculiarity has offered itself to those who have suffered by drowning, and have been subsequently restored. They have related that in their moment of supreme agony, the whole series of events of their past life has, as it were, flowed in an instant upon them with the most appalling vividness, their good and evil works, and even the most trifling incidents presenting themselves with distinctness—a tide of memory.

From what source are these suggestions derived? What is meant by the instantaneous presentment of events?

OF DEATH.

At all periods of life, the functional activity of the system occasions a waste of its tissues by the interstitial death of their parts, and therefore involves a necessity of repair. So long as the reparation balances the waste, a healthy equilibrium is maintained; but when the nutritive powers decline, as old age approaches, a gradual deterioration of the system ensues.

The period of greatest activity is also that of greatest waste, and of the most active and perfect repair, interstitial death and the removal of decayed material then occurring in the most rapid manner. The energy of life is thus dependent on the amount and completeness of death.

At a later period, with advancing years, although the loss of substance through functional activity may be lessened, the renewal and restoration of the portions which are necessarily consumed are far more than correspondingly diminished. We thus become incapacitated corporeally and mentally, and, if no accident intervenes, we die through mere old age.

The death of individuals may therefore occur in two ways, by accident or by old age. But death from old age is very unusual, for even in the case of those who are very far advanced in life, its close is ordinarily brought about by some lesion or derangement of the vital organs, thus, in reality, constituting accidental death.

Most men desire that their final scene may be attended with as little derangement as possible of their ordinary mental powers, and that it may be very brief. If this constitute the euthanasia, or happy death, it certainly can not be thought that extreme old age is desirable, constituting, as it does, a long-continued and dreary disease. The senses fail us in the same manner and in the same order that they do when we are falling asleep, their gradual deterioration bringing us back to the helplessness and imbecility of infancy. In the long interval during which this is going on, the aged man is not

How is it that deterioration of the system inevitably occurs? How is it that eventually death necessarily takes place? Why is it that death from old age is so unusual?

only a burden to himself, but a sad spectacle to every one around him; his perceptions are being gradually blunted; and though he is, as it were, by degrees passing into a final slumber, it is in that disturbed way which all have witnessed when they fall asleep after severe fatigue.

The different portions of the body die in succession: the system of animal life before that of organic, and of the former the sensory functions fail first, voluntary motion next, while the power of muscular contraction under external stimulus still feebly continues. The blood, in gradual death, first ceases to reach the extremities, its pulsations becoming less and less energetic, so that, failing to gain the periphery, it passes but a little way from the heart; the feet and hands become cold as the circulating fluid leaves them, the decline of temperature gradually invading the interior. No one has ever yet offered a more accurate picture of the appearence of the dying than that presented by Hippocrates: "If the patient lies on his back, his arms stretched out, and his legs hanging down, it is a sign of great weakness; when he slides down in the bed it denotes death. If, in a burning fever, he is continually feeling about with his hands and fingers, and moves them up before his face and eyes as if he were going to take away something before them, or on his bed-covering as if he was picking or searching for little straws, or taking away some speck, or drawing out little flocks of wool, all this is a sign that he is delirious, and that he will die. When his lips hang relaxed and cold, when he can not bear the light, when he sheds tears involuntarily, when, dozing, some part of the white of the eye is seen, unless he usually sleeps in that manner, these signs prognosticate danger. When his eyes are sparkling, fierce, and fixed, he is delirious, or soon will be so; when they are deadened, as it were, with a mist spread over them, or their brightness lost, it presages death or great weakness. When the patient has his nose sharp, his eyes sunk, his temples hollow, his ears cold and contracted, the skin of his forehead tense and dry, and the color of his face tending to a pale green or leaden tint, one may give out for certain that death is very near, unless the strength

In what order do the different parts of the body die? Describe the Hippocratic face.

of the patient has been exhausted all at once by long watchings, or by a looseness, or being a long time without eating."

Physiologists often quote the sentiment of Montaigne, "With how little anxiety do we lose the consciousness of light and of ourselves." By this they would convey the idea that the act of dying is as painless as the act of falling asleep, and also as little perceived. They recall the fact which seems to support this view, that those who have been recovered after apparent death from drowning, and after sensation has been totally lost, report that they have experienced no pain; and, indeed, when we reflect that the sensory powers are the first to decline, the eye and the ear, at an early period in the article of death, failing to discharge their duty, and the general sense of touch becoming rapidly more and more obtuse, we can scarcely put any other interpretation upon the final struggles constituting what is so significantly called the agony, than that they are purely automatic and therefore unfelt. Doubtless the mind, in this solemn moment, is sometimes occupied with an instantaneous review of impressions long before made upon the brain, and which offer themselves with clearness and energy now that present circumstances are failing to excite its attention, through loss of sensorial power of the peripheral organs, this state of things having also been testified to by those who have been recovered from drowning.

Life closes at last in various ways. Some pass away as though they were really falling asleep; others with a deep sigh or groan; others with a gasp; and some with a convulsive struggle.

What reason is there to suppose that the final agony is automatic?

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